EFFECT OF USING MINERAL ADMIXTURES ON PROPERTIES OF CONCRETE BY ADDITION OF BASALT FIBERS

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Abstract

Concrete is a mixture of cement, fine aggregate, coarse aggregate and water. The main challenge is to meet the increase in demand and cost of concrete in sustainable manner in civil engineering field. To overcome these challenges a study is to be conducted to determine the use of industrial wastes in concrete making which leads to a greener environment.

In this study the effect of replacing Metakaolin (MK) with cement to improve the performance of concrete, Mixes with different percentages i.e., 5%, 10% and 15% proportions of MK are designed. The physical and mechanical properties are determined and these results shown by replacing of cement with MK can improve the properties of concrete. After optimizing the MK%, the developed mix of MK is further added to silica fumes (SF) with different percentages i.e., 2.5%, 5% and 7.5%. The properties are evaluated and compared with conventional mix. Further by adding of basalt fibers with varying percentages i.e., 0.0%, 0.4%, 0.8% and 1.2%. Adding basalt fibres to concrete can increase the concrete's durability. It reduces crack growth and increases impact strength and tensile strength.

Keywords: Metakaolin(MK), Silica fume(SF), Basalt fibers(BF)

1. INTRODUCTION

Concrete is the second-most-used engineering material in the world, behind only water and the addition of other components can alter the properties of concrete. It is the composite material that is most frequently utilized to build high-rise structures and other infrastructure projects, especially in emerging nations like India. Concrete is created by combining water, fine and coarse material, and cement. Because of its obvious advantages, such as compressive strength, fire resistance, freeze-thaw resistance, and durability performance, reinforced concrete is still a widely utilized building material. It is a composite material comprised of steel and concrete. Concrete is a heterogeneous material that is formed of cement and particles of various sizes and forms. 5 to 7% of all carbon dioxide emissions worldwide are attributed to the cement sector. Global cement production is 5.9 billion tons annually in 2020, producing 4.8 billion tons of CO_2. Environmentally hazardous greenhouse gases like SO_3 and NO_x are also byproducts of the cement making process. As part of the cement production process, significant amounts of energy and raw materials are also used. The ever-expanding population and physical characteristics that are felt both locally and worldwide can be ascribed to the rising demand for future development. The majority of these developments are anticipated to take place in marine and coastal areas because of the opportunities for fair trade and transportation, the suitability of these sites for establishing human settlements, and the ease of access they provide. The structural and aesthetic performance of RC constructions is, however, being negatively impacted by a number of important concerns. Poor design and construction techniques, poor material choices, and exposure to harsh environmental conditions, such as a chloride-rich environment, are some of these issues. The deterioration and breakdown of reinforced concrete structures in coastal and maritime locations may significantly affect societal sustainability, economy, and safety. The principal factor impacting the long-term performance of reinforced concrete structures in coastal and marine environments is chloride attack. The physical and chemical processes linked to the deterioration of the concrete microstructure and the corrosion of the steel rebar are significantly influenced by chloride ingress as well. The development of fractures, spalling, and a decrease in the load-bearing capacity in reinforced concrete structures are caused by the spread of chloride assault, which is started by the expansion/contraction and hydration/dehydration cycles. Changes in temperature and humidity in chloride-rich environments have a direct impact on the cycles. In the end, this can result in less-durable concrete coastal and marine constructions that are unsafe. Premature failure can result in significant financial loss, in addition to the expense of repairs. In this context, it is crucial to create strong concrete structures with a longer lifespan and fewer damages from unforeseen causes. To improve the mechanical, durability, and fresh state performance of concrete exposed to chloride-laden environments, alternative binder ingredients are typically added. The benefits of using alternative binder systems, such as Metakaolin (MK) and Silica Fume (SF), to partially replace cement have been widely studied in a number of research investigations. Some of these effects include lowered heat of hydration, greater durability, and increased resistance to chloride attack in concrete.

Metakaolin (MK) is a Pozzolanic substance that is extremely reactive and has better properties for concrete performance. Metakaolin (($Al_2Si_2O_5$)orAS_2) is created through the hydroxylation process, which involves heating the natural clay mineral kaolin (($Al_2Si_2O_5(OH)_4$) or AS_2H_4) to a temperature between 650°C and 800°C. Aluminosilicate material MK contains silica (50%–55%) and alumina (40%–45%) in various proportions. It normally comes in the form of a white powder with particles that are much smaller than Portland cement particles, measuring around 2 µm in diameter. MK is well known for its beneficial impact on enhancing the performance of concrete, which is accomplished by interacting with accessible calcium hydroxide/Portlandite to produce secondary calcium silica hydrate (C-S-H) and several other hydrates (C_4AH_{13}, C_3AH_6 and C_2ASH_8 or Stratlingite)

Silica fume is mostly made up of non-crystalline silica, which is a byproduct of the production of silicon metal and ferrosilicon alloys in electric furnaces. The primary spherical particles in silica fume have an average diameter of around 0.15µm and an extraordinarily high specific surface area that ranges from 13,000 to 30,000 m^2/kg. Every SF particle is thought to be 100 times smaller than a typical cement particle. High performance concrete can be made with silica fume, one of the most used pozzolanic materials, to increase strength, considerably increase impermeability, and increase durability. MK particles are typically between 0.5 to 5µm in size, which makes them smaller than PC particles but larger than SF particles. MK and SF are both frequently added to concrete at a rate of 5 to 10% to replace PC in part. Unlike MK, which is white, standard SF has a color range from grey to black. The manufacturing of high-performance concrete and architectural applications where white and lighter colors are preferred make MK highly appealing.

The thermal resistance of basalt fiber is exceptional. Olivine and nepheline are two important minerals found in basalt that are responsible for the fiber drawing. Steel can be replaced with basalt base composite because 1 kg of basalt can compete with 9.6 kg of steel. Basalt fiber ranges in density from 2.8 to 2.9 g/cc. The strength of basalt fiber surpasses that of glass but its density is less than that of steel. Certain geographically specific basalt fibers are capable of battling in the pH range of roughly 13.0-14.9. Basalt fiber has a tensile strength of roughly 4,800 MPa.

2. LITERATURE REVIEW

Deveshan L. Pillay a , Oladimeji B. Olalusi (2021) were studied the engineering properties of metakaolin (MK) based concrete exposed to chloride attack. It was found that MK had a significant effect on the long-term compressive strength and a marginal effect on the flexural strength. It was also found that MK improved the pore structure of concrete. The samples containing MK displayed a more cohesive matrix, with large extents of C–S–H gels present, which is responsible for preventing the ingress of chloride ions.

It can be concluded that MK is a feasible option as an alternate binder system for combatting chloride attack in concrete structures situated at coastal/marine environment.

Gaurav chand, Sugandh Kumar Happy, Shobha Ram(2021) were investigate the Assesment of the properties of sustainable concrete produced from quaternary blend of portland cement, glass powder, metakaolin and silica fume. The study shows the Partial replacement of OPC with silica fume and metakaolin. It was found that The 5% replacement of cement with metakaolin shows better strength and 15% replacement of cement with silica fume is found to be optimum in enhancing the strength of the concrete due to the formation of C-S-H gel in the mixture.

Liyun Yang, Huanzhen Xie , Shizheng Fang, Chen Huang, Aiyun Yang, Yuh J. Chao(2021) were studied on mechanical properties and damage mechanism of basalt fiber reinforced concrete under uni-axial compression. In this study, the effects of basalt fiber content on the uni-axial compressive mechanical properties and damage of concrete were investigated. It was found that the proper amount of basalt fiber (6 kg/m^3) improves the compressive strength and peak strain of concrete. However, excessive basalt fibers reduce the compressive strength of concrete, and the peak strain.

The proper amount of basalt fiber (6 Kg/m^3) can delay the early cracking of concrete. With the increase in basalt fiber content, the long cracks on the concrete surface gradually change into many microcracks. The proper amount of basalt fiber (6 kg/m^3) reduces the transverse strain of concrete, whereas excessive basalt fibers exhibit an opposite trend.

Yuanbo Du, Wencui Yang, Yong Ge, Sha Wang, Liu Penghuan(2020) were studied the thermal conductivity of cement paste containing waste glass powder, metakaolin and limestone filler as supplementary cementitious material. It was found that by increasing the amount of MK from 0 to 25% the thermal conductivity and compressive strength of cement paste increased by 54% and 43% respectively.

The addition of MK could siginificantly reduce total porosity, most probable pore size, transitional pores and capillary pore of cement due to the pozzolanic activity and filling effect of MK.

V. Nezerka, P.Bily, V.Hrbek, J.Flaadr(2019) were studied the Impact of Silica fume, Flyash and Metakaolin on the thickness and strength of the ITZ in concrete. This study presents the Partial replacement of supplementary cementitious material with silica fume and metakaolin. It was found that Addition of secondary cementitious materials can enhance an ITZ by reducing its thickness and increasing in strength, silica fume is more efficient in reducing ITZ thickness.

Yuanxun Zheng, Peng Zhang, Yingchun Cai, Zuquan Jin, Ehsan Moshtagh(2018) were investigated on Cracking resistance and mechanical properties of basalt fibers reinforced cement stabilized macadam. It was found that the Increasing basalt fibers content would cause lower workability, but the workability can be improved by adding the naphthalene superplasticizer at the dosage of 0.2%–0.3%.Basalt fibers reinforcement effect on compressive strength of cement-stabilized macadam material is limited, and with the increase of basalt fibers content, the compressive strength of different series mix increased nonlinearly. When the basalt fibers content was 6Kg / m^3, the compressive strength was increased by 7.6%.

Mohammed Seddik Meddah, Mohamed A. Ismail, Sherif El-Gamal, Heni Fitriani(2018) Were studied the performances evaluation of binary concrete designed with silica fume and metakaolin. It was found that The use of SF and MK both require an increasing amount of superplasticizer with a rise in the level of PC substitution by SF/MK, while SF appears to need more due to its higher fineness than MK.

The amount of water needed to achieve the desired consistency after adding SF or MK to concrete has increased. With an increase in PC substitution by SF/MK, this amount of water likewise rises. At all evaluated ages and w/cm ratios, the compressive strength of both SF/MK-concretes rises with an increase in PC replacement level.

Mehmet Emin Arslan(2016) were studied the Effect of basalt and glass chopped fibers addition on fracture energy and mechanical properties of ordinary concrete. The investigation shows the Partial replacement of supplementary cementitious material with basalt fiber. It was found that the addition of basalt fibers up to 2%, increases the split tensile strength and flexural strength of concrete.

Mahdi valipour, farhad pargar, mohammad shekarchi, sara khani(2013) were studied the Comparing a natural Pozzolan, Zeolite to Metakaolin and Silica fume in terms of their effect on the durability characteristics of concrete. It was found that the concrete shows an increase in compressive strength when the metakaolin and silicafume are replaced with cement at 7.5-10% and 10-15%.

3. MATERIALS AND ITS PROPERTIES

Cement

The ordinary Portland cement of 53 grade confirming to IS 12269-2013 has been used in this investigation. It was fresh and free of lumps. The physical characteristics as determined by different test in accordance with Indian standard IS 12269:2013. The various tests performed on cement is shown in Table 3.1

Table 3.1 Physical properties of Ordinary Portland cement.

S.NO	Property	Test result
1.	Fineness	4 gms

2.	Consistency	28%
3.	Specific gravity	3.04
4.	Initial setting time	40
5.	Final setting time	280
6.	Blaine air permeability (m^2/kg) Specific surface area	263.2 m^2/kg

Fine aggregate & Coarse aggregate

Fine aggregate for the experimental program had been locally obtained and conformed to grading zone II as per IS: 383-2016. Fine aggregate was initially sieved through 4.75mm sieve to remove any particles greater than 4.75mm after which it was washed to remove and dust. Coarse aggregates used in this study are locally available granite-type coarse aggregates with nominal size of 20mm and 12mm. laboratory tests on coarse aggregate performed in accordance with IS : 2386 part(3)-1963 to determine the various physical properties and they can be shown in the table follows

Table 3.2 physical properties of fine aggregate and coarse aggregate

S.NO	Property	Fine Aggregate Test result	Coarse Aggregate(20mm) Test result	Coarse Aggregate(12mm) Test result
1.	Specific gravity	2.77	2.8	2.79
2.	Fineness modulas	2.66	2.88	-
3.	Bulk density (without compaction)	1403.77kg/m^3	1279.24kg/m^3	-
4.	Bulk density (with compaction)	1483.96kg/m^3	1402.83kg/m^3	-
5.	Water absorption	0.8%	0.5%	0.5%
6.	Zone	II	--	-

Metakaolin & Silica fume

Table 3.3 Chemical composition of Metakaolin & Silica fume.

S.NO	Chemical composition	Metakaolin	Silica fume
1.	SiO_2	52.0%	99.886%
2.	Al_2O_3	46.0%	0.043%
3.	Fe_2O_3	0.6%	0.040%
4.	TiO_2	0.65%	0.001%
5.	CaO	0.09%	0.001%
6.	MgO	0.03%	0.000%
7.	Na_2O	0.10%	0.003%
8.	K_2O	0.03%	0.001%
9.	Loss of Ignition	0.50%	0.015%

Superplasticizer

Superplasticizer used is Conplast SP430 DIS.

Conplast SP430 DIS is based on Sulphonated Naphthalene polymers and supplied as a brown liquid instantly dispersible in water. Conplast SP430 DIS complies with IS:9103, BS:5075 and ASTM-C-494 type 'A' and type 'G' depending on dosages. It has been specially formulated to give high water reductions without loss of workability or to produce high quality concrete of reduced permeability.

Specific gravity is 1.2

Chloride content is NIL (as per BS 5075 part 1)

Air entrainment as per IS 9103

Basalt fibers

Basalt fiber is a material made from extremely fine fibers of basalt, which is composed of the minerals plagioclase, pyroxene, and olivine. It is similar to fiberglass, having better physico mechanical properties than fiberglass, but being significantly cheaper than carbon fiber. It has a similar chemical composition as glass fiber but has better strength characteristics, and unlike most glass fibers is highly resistant to alkaline, acidic and salt attack making it a good candidate for concrete, bridge and shoreline structures. The density of basalt fibers is 2.8 g/cc, the tensile strength is 4840 MPa, Elastic Modulas is 89GPa, Elongation at break is 3.15%, linear expansion coefficient 5.5×10^3.

4. Mix proportions

Concrete mix design as per IS:10262-2019 was adopted in this work for preparing mixes. Initially one conventional mix was prepared i.e., control mix. In intial stage mixes were prepared by replacing cement with Metakaolin(MK) in different percentages i.e., 5%, 10% and 15%. After analyzing the results the developed mix of Metakaolin(MK) is further replacing cement with silica fumes (SF) in different percentages i.e., 2.5%, 5% and 7.5% were done. For the optimized mix, basalt fibers are added with varying percentages 0.0%, 0.4%, 0.8% and 1.2%.

For all mixes laboratory tests for workability of concrete and the hardened properties like compressive strength, split tensile strength, flexural strength and water absorption ratio were tested. The mix proportions are shown in below table.

Table 4.1 Mix proportions for cement replacement with Metakaolin

Mix	W/C	water	Type	percent	quantity	cement	Fine aggregate	Coarse aggregate	SP
Control mix	0.45	174.25	C 100	0%	387.2	387.2	673.80	1264.9	2.62
Mix 1	0.45	174.25	MK 5 C 95	5% 95%	19.36 367.84	367.84	673.80	1264.9	2.62
Mix 2	0.45	174.25	MK10 C 90	10% 90%	38.72 348.48	348.48	673.80	1264.9	2.62
Mix 3	0.45	174.25	MK15 C 85	15% 85%	58.08 329.12	329.12	673.80	1264.9	2.62

Table4.2 Mix proportions for Cement replacement with Silica fume and keeping Metakaolin constant @ 10%

Mix	W/C	water	Type	percent	quantity	cement	Fine aggregate	Coarse Aggregate	SP
Control mix	0.45	174.25	C 100	0%	387.2	387.2	673.80	1264.9	2.62
Mix 4	0.45	174.25	MK 10 SF 2.5 C 87.5	10% 2.5% 87.5%	38.72 9.68 338.8	338.8	673.80	1264.9	2.62
Mix 5	0.45	174.25	MK 10 SF 5 C 85	10% 5% 85%	38.72 19.36 329.12	329.12	673.80	1264.9	2.62
Mix 6	0.45	174.25	MK 10 SF 7.5 C 82.5	10% 7.5% 82.5%	38.72 29.04 319.44	319.44	673.80	1264.9	2.62

Table 4.3 Mix proportions for addition of Basalt fibers to the optimum mix where cement replacement with Silica fume & Metakaolin constant

Mix	W/C	water	Type	percent	quantity	cement	Fine aggregate	Coarse Aggregate	SP
Control mix	0.45	174.25	C 100	0%	387.2	387.2	673.80	1264.9	2.62
Mix 7	0.45	174.25	MK 10 SF 2.5 C 87.5 BF 0.4	10% 2.5% 87.5% 0.4%	38.72 9.68 338.8 1.548	338.8	673.80	1264.9	2.62

Mix 8	**0.45**	**174.25**	**MK 10** **SF 2.5** **C 87.5** **BF 0.8**	**10%** **2.5%** **87.5%** **0.8%**	**38.72** **19.36** **329.12** **3.097**	**329.12**	**673.80**	**1264.9**	**2.62**
Mix 9	**0.45**	**174.25**	**MK 10** **SF 2.5** **C 87.5** **BF 1.2**	**10%** **2.5%** **87.5%** **1.2%**	**38.72** **29.04** **319.44** **4.646**	**319.44**	**673.80**	**1264.9**	**2.62**

5. Results and Discussion

5.1 Mechanical Properties

5.1.1 Compressive Strength

The compressive strength results of the samples represented in the following graphs as shown in below. The 28 days compressive strength of conventional mix (M 35) is 44.3MPa. The 5% Metakaolin(MK) replacement mixture had exhibited slightly higher 28 days compressive strength is 50MPa which is 11% more when compared to 28days compressive strength of conventional mix. The 28 days compressive strength of 10% MK replacement mixture 53MPa which is 16% more when compared to 28days compressive strength of the conventional mix. The 28 days compressive strength of 15% MK replacement mixture is 45.3MPa which is 2.2% more when compared to conventional mix. The optimum results were obtained at 10%MK replacement mixture.

Table 5.1 28 days compressive strength of concrete by partial replacement of cement with metakaolin

Mix	Type of concrete	28 days compressive strength (MPa)
Mix 0 (control mix)	Conventional concrete (M35)	44.3
Mix 1	MK 5%, C 95%	50
Mix 2	MK 10%, C 90%	53
Mix 3	MK 15%, C 85%	45.3

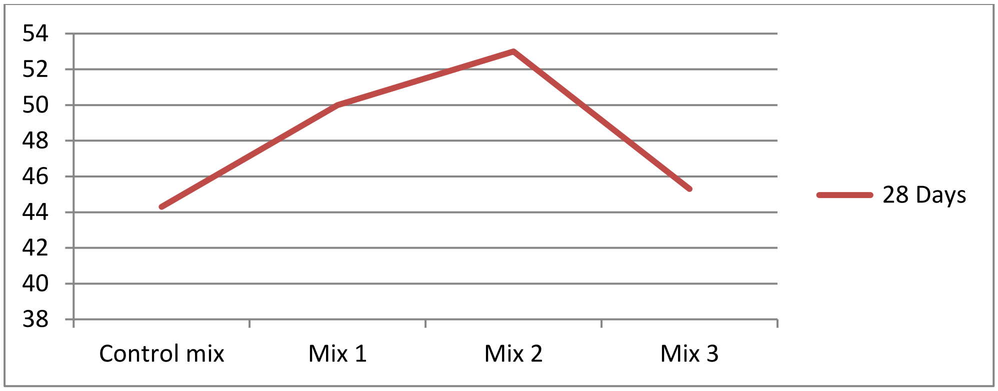


Fig 5.1 compressive strength for 28 days

The optimum results were obtained at 10%MK replacement mixture. By keeping 10% MK as a constant, replace the cement with Silicafume(SF) from 2.5% -7.5% with an increment of 2.5% . The 28 days compressive strength of Mix with 2.5% SF and 10% MK is 57MPa which is 22.2% higher than the conventional mix. The 28 days compressive strength of mix with 5%SF and 10% MK is 51MPa which is 13.13% higher than the conventional mix, the 7.5% SF and 10% MK mixture 28 days compressive strength is 51MPa which is 13.13% higher than the conventional mix. The optimum results are obtained when the SF is replaced by 2.5% and MK is 10%. By keeping MK 10% and SF 2.5% as a constant, additionally we are adding Basalt fibers upto 1.2% by weight of cementitious material.

Table 5.2 28 days compressive strength of concrete by partial replacement of cement

with silica fume and keeping Metakaolin constant @10%

Mix	Type of concrete	28 days compressive strength (MPa)
Mix 0 (control mix)	Conventional concrete (M35)	44.3
Mix 4	MK 10%, C 87.5%, SF 2.5%	57
Mix 5	MK 10%, C 85% SF 5%	51
Mix 6	MK 10%, C 82.5% SF 7.5%	51

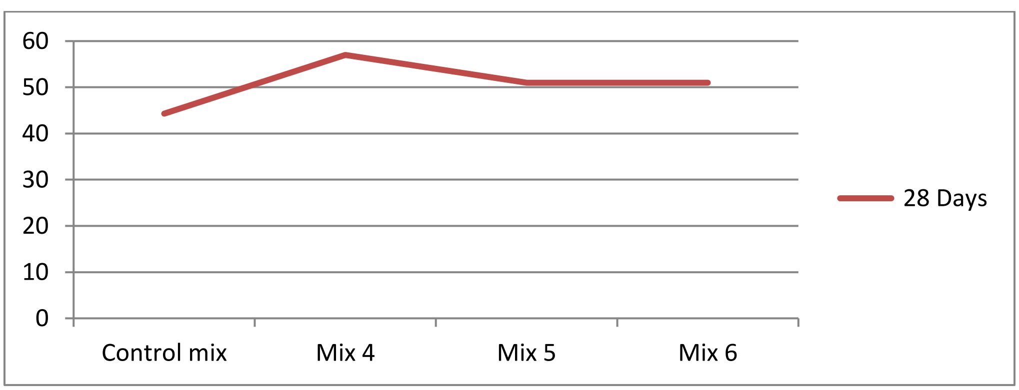


Fig 5.2 compressive strength for 28 days

By keeping MK 10% and SF 2.5% as a constant, additionally we are adding Basalt fibers upto 1.2% by weight of cementitious material The 28 days compressive strength of the mixture with 0.4% of basalt fibers is 53.33MPa which is 16.4% higher than the conventional mix. Mix with 0.8% of basalt fibers had obtained 60.6MPa as 28days compressive strength, which is 26.89% higher than the conventional concrete. The 28 days compressive strength of the mix with 1.2% of basalt fibers is 55.6MPa, which is 20% higher than the conventional concrete. The optimum results are obtained at a particular mix, where 0.8% basalt fibers added additionally to the conventional concrete which is already incorporated with 2.5%SF and 10%MK.

Table 5.3 28 days compressive strength of concrete by addition of basalt fibers

And keeping silica fume constant @2.5% , Metakaolin constant @10%

Mix	**Type of concrete**	**28 days compressive strength (MPa)**
Mix 0 (control mix)	Conventional concrete (M35)	44.3
Mix 7	MK 10%, C 87.5%, SF 2.5%, BF 0.4%	53.3
Mix 8	MK 10%, C 87.5% SF 2.5%, BF 0.8%	60.6
Mix 9	MK 10%, C 87.5% SF 2.5%, BF 1.2%	55.6

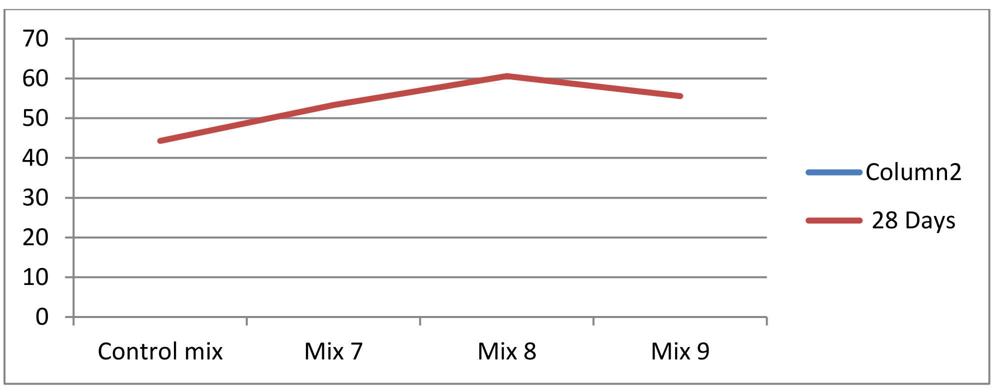


Fig 5.3 compressive strength for 28 days

5.1.2 Flexural strength

Flexural strength test. The flexural strength of concrete is determined using flexural testing machine, by casting beams of standard dimensions 100mm × 100mm × 500mm. The testing is done at 28 days as per IS 516, under normal room temperature.

The Flexural strength results of the samples represented in the following graphs as shown in below. The 28 days flexural strength of conventional mix (M35) is 6.44 MPa. The 5% Metakaolin(MK) replacement mixture had exhibited slightly lower 28 days flexural strength i.e., 6.25MPa which is 2.9% lesser than conventional mix. The 28 days flexural strength of 10% MK replacement mixture is 6.22MPa which is 3.4% less when compared to 28days flexural strength of the conventional mix. The 28 days flexural strength of 15% MK replacement mixture is 6.31MPa which is 2% less when compared to conventional mix. The optimum results (Compressive strength) were obtained at 10%MK replacement mixture.

Table 5.4 28 days Flexural strength of concrete by partial replacement of cement with metakaolin

Mix	Type of concrete	28 days flexural strength (MPa)
Mix 0 (control mix)	Conventional concrete (M35)	6.44
Mix 1	MK 5%, C 95%	6.25
Mix 2	MK 10%, C 90%	6.22
Mix 3	MK 15%, C 85%	6.31

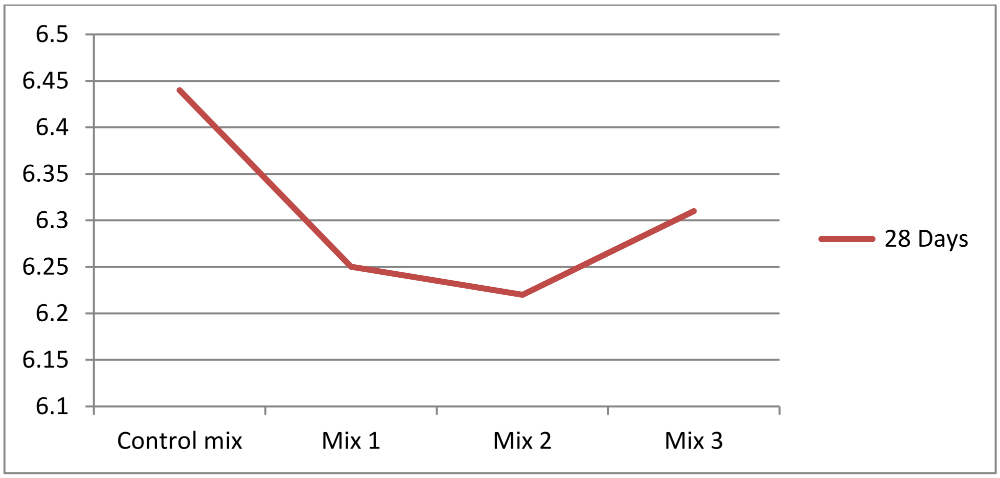


Fig 5.4 Flexural strength for 28 days

By keeping 10% MK as a constant, replace the cement with Silicafume(SF) from 2.5% -7.5% with an increment of 2.5% . The 28 days flexural strength of Mix with 2.5% SF and 10% MK is 5.95MPa which is 7% lesser than the conventional mix. The 28 days flexural strength of mix with 5%SF and 10% MK is 5.7MPa which is 11% lesser than the conventional mix. The 7.5% SF and 10% MK mixture had exhibited slightly lower 28 days flexural strength i.e., 5.34MPa which is 17% lesser than the conventional mix. The optimum results(Compressive strength) are obtained when the SF is replaced by 2.5% and MK is 10%.

Table 5.5 28 days flexural strength of concrete by partial replacement of cement

with silica fume and keeping Metakaolin constant @10%

Mix	Type of concrete	28 days flexural strength (MPa)
Mix 0 (control mix)	Conventional concrete (M35)	6.44
Mix 4	MK 10%, C 87.5%, SF 2.5%	5.95
Mix 5	MK 10%, C 85% SF 5%	5.7
Mix 6	MK 10%, C 82.5% SF 7.5%	5.34

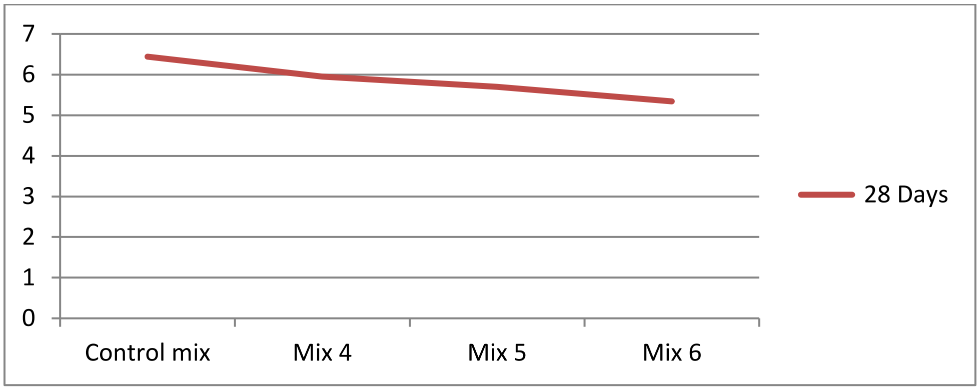


Fig 5.5 Flexural strength for 28 days

By keeping MK 10% and SF 2.5% as a constant, additionally we are adding Basalt fibers upto 1.2% by weight of cementitious material. The 28 days flexural strength of the mixture with 0.4% of basalt fibers is 6.13MPa which is 4% lesser than the conventional mix. Mix with 0.8% of basalt fibers had obtained 6.93MPa as 28days flexural strength, which is 7% higher than the conventional concrete. The 28 days flexural strength of the mix with 1.2% of basalt fibers is 6.05MPa, which is 6% higher than the conventional concrete. The optimum results are obtained at a particular mix, where 0.8% basalt fibers added additionally to the conventional concrete which is already incorporated with 2.5%SF and 10%MK.

Table 5.6 28 days compressive strength of concrete by addition of basalt fibers

And keeping silica fume constant @2.5% , Metakaolin constant @10%

Mix	**Type of concrete**	**28 days flexural strength (MPa)**
Mix 0 (control mix)	Conventional concrete (M35)	6.44
Mix 7	MK 10%, C 87.5%, SF 2.5%, BF 0.4%	6.13
Mix 8	MK 10%, C 87.5% SF 2.5%, BF 0.8%	6.93
Mix 9	MK 10%, C 87.5% SF 2.5%, BF 1.2%	6.05

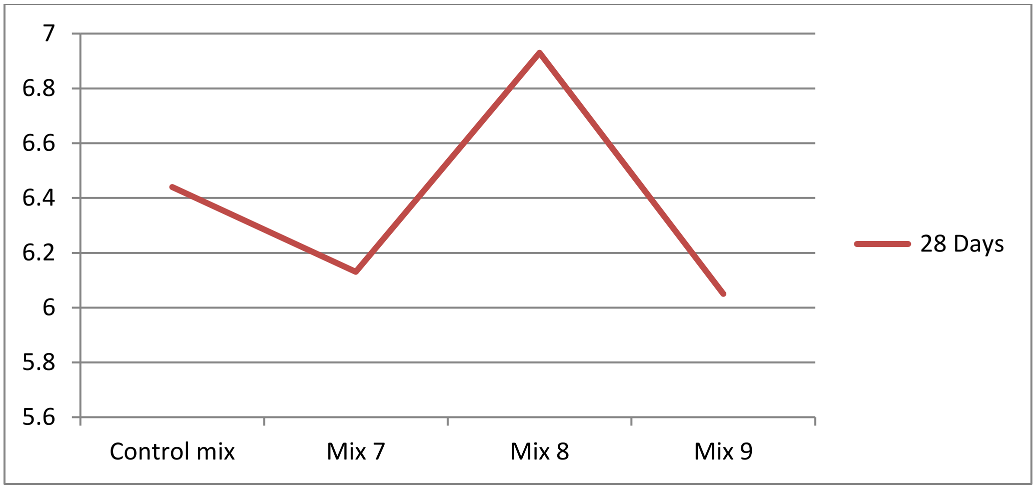


Fig 5.6 Flexural strength for 28 days

5.1.3 Split tensile strength

Splitting tensile strength test, It is an indirect test to determine the tensile strength of cylindrical specimen, which is performed on the compressive testing machine. The cylindrical specimen of size of 100mm diameter and 200mm length are tested at 28 days, under normal room temperature, as per IS 5816.

The split tensile strength results of the samples represented in the following graphs as shown in below. The 28 days split tensile strength of conventional mix (M35) is 4.77 MPa. The 5% Metakaolin(MK) replacement mixture had exhibited slightly lower 28 days split tensile strength i.e., 4.82MPa which is 1% higher than conventional mix. The 28 days split tensile strength of 10% MK replacement mixture is 4.45MPa which is 6% less when compared to 28days split tensile strength of the conventional mix.

The 28 days split tensile strength of 15% MK replacement mixture is 4.45MPa which is 6% less when compared to conventional mix. The optimum results (Compressive strength) were obtained at 10%MK replacement mixture.

Table 5.7 28 days split tensile strength of concrete by partial replacement of cement with metakaolin

Mix	Type of concrete	28 days split tensile strength (MPa)
Mix 0 (control mix)	Conventional concrete (M35)	4.77
Mix 1	MK 5%, C 95%	4.82
Mix 2	MK 10%, C 90%	4.45
Mix 3	MK 15%, C 85%	4.45

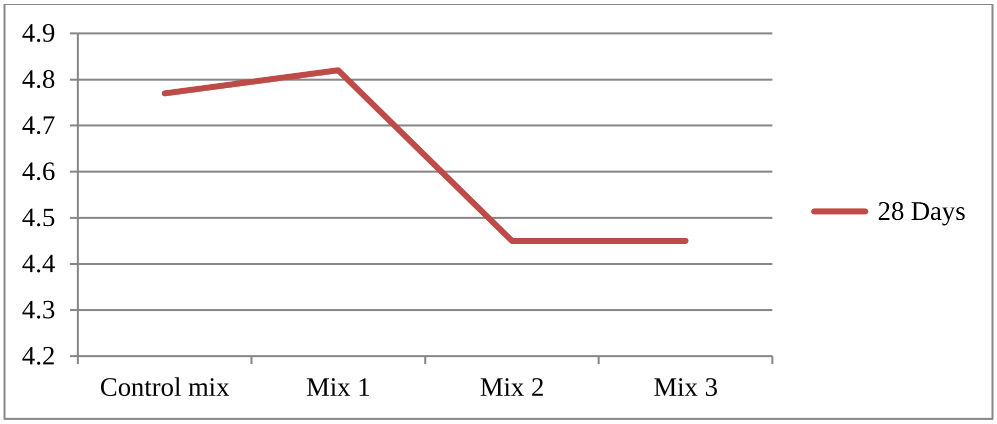


Fig 5.7 Split tensile strength for 28 days

By keeping 10% MK as a constant, replace the cement with Silica fume(SF) from 2.5% -7.5% with an increment of 2.5% . The 28 days split tensile strength of Mix with 2.5% SF and 10% MK is 4.93MPa which is 3.2% higher than the conventional mix. The 28 days split tensile strength of mix with 5%SF and 10% MK is 4.45MPa which is 6% lesser than the conventional mix. The 7.5% SF and 10% MK mixture had exhibited slightly higher 28 days split tensile strength i.e., 4.93MPa which is 3% higher than the conventional mix. The optimum results(Compressive strength) are obtained when the SF is replaced by 2.5% and MK is 10%.

Table 5.8 28 days split tensile strength of concrete by partial replacement of cement

with silica fume and keeping Metakaolin constant @10%

Mix	**Type of concrete**	**28 days split tensile strength (MPa)**
Mix 0 (control mix)	Conventional concrete (M35)	4.77
Mix 4	MK 10%, C 87.5%, SF 2.5%	4.82
Mix 5	MK 10%, C 85% SF 5%	4.45
Mix 6	MK 10%, C 82.5% SF 7.5%	4.45

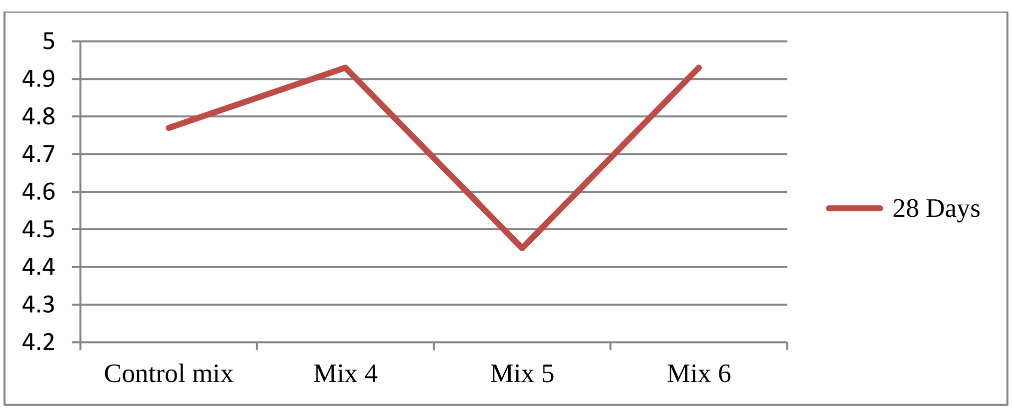


Fig 5.8 Split tensile strength for 28 days

By keeping MK 10% and SF 2.5% as a constant, additionally we are adding Basalt fibers upto 1.2% by weight of cementitious material. The 28 days split tensile strength of the mixture with 0.4% of basalt fibers is 4.77MPa which is equal to the conventional mix. Mix with 0.8% of basalt fibers had obtained 5.09MPa as 28days split tensile strength, which is 6.2% higher than the conventional concrete. The 28 days split tensile strength of the mix with 1.2% of basalt fibers is 4.61MPa, which is 3% higher than the conventional concrete. The optimum results are obtained at a particular mix, where 0.8% basalt fibers added additionally to the conventional concrete which is already incorporated with 2.5%SF and 10%MK.

Table 5.9 28 days split tensile strength of concrete by addition of basalt fibers

And keeping silica fume constant @2.5% , Metakaolin constant @10%

Mix	Type of concrete	28 days split tensile strength (MPa)
Mix 0 (control mix)	Conventional concrete (M35)	4.77
Mix 7	MK 10%, C 87.5%, SF 2.5%, BF 0.4%	4.77
Mix 8	MK 10%, C 87.5% SF 2.5%, BF 0.8%	5.09
Mix 9	MK 10%, C 87.5% SF 2.5%, BF 1.2%	4.61

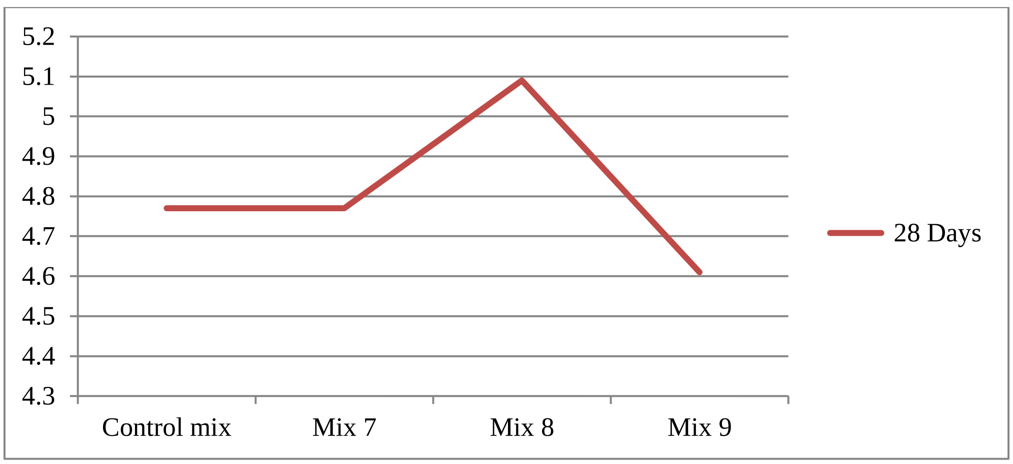


Fig 5.9 Split tensile strength for 28 days

5.2 DURABILITY PROPERTIES

5.2.1 ACID ATTACK

Acid attack test is done to determine the durability of specimens prepared from different replacements percentages. The concrete cubes of control or conventional mix and remaining mixes are casted and cured for 28 days, their initial weights (dry weight) is noted. Further, the cubes are immediately submerged into the solution of 0.2N of H_2SO_4 solution for 90 days. After 90 days the samples are taken out from the solution and their reduced weights is measured. Similarly the compressive strength is measured for all the specimens. The acid curing is performed for control mix and hybrid mixes for 90 days and it is found that the white precipitate is developed on the outer surface of concrete. The compressive strength is measured for water cured concrete after 28 days and acid cured concrete for 90 days.

Table 5.10 Percentage Weight Loss Due to Acid Attack Test Results

S.No	Mixes	Compressive Strength after 28 days of normal curing (MPa)	Compressive Strength after 90 days of acid curing (MPa)	Reduction in strength	Reduction in weight
1.	Mix 0	44.3	27	39.05 %	9.7 %
2.	Mix 2	57	35	38.9 %	2.5 %
3.	Mix 4	59	49	16.9 %	6.5 %
4.	Mix 8	60.6	30	50.4 %	7.2 %

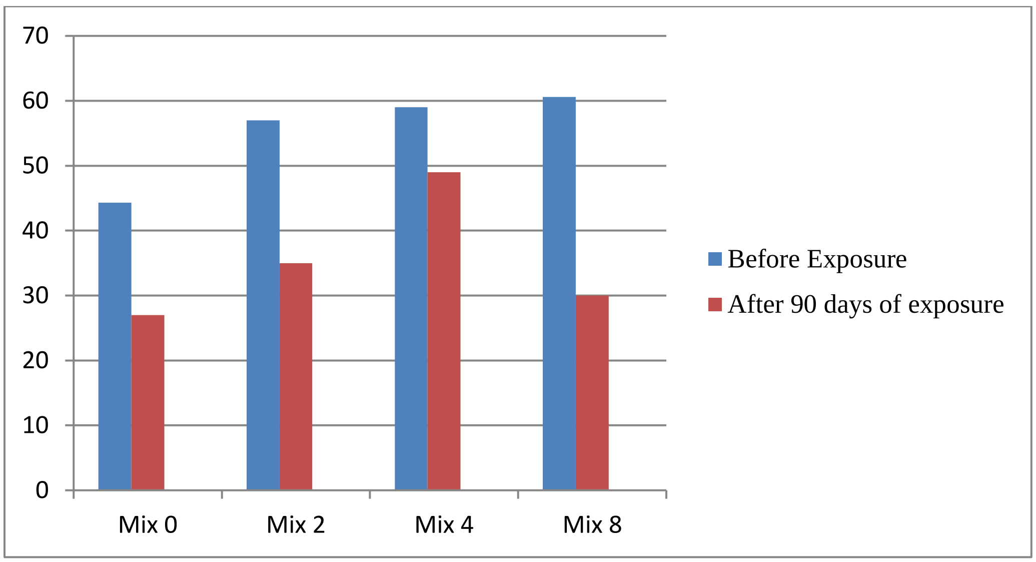


Fig 5.10 Percentage Weight Loss Due to Acid Attack Test Results

It is found that the compressive strength for control mix reduces by 39.05%, where as for mix 2 the compressive strength is reduced by 38.9%, for mix 4 the compressive strength is reduced by 16.9%, for mix 8 it is noticed that the reduction is 50.4%. it is observed that a reduction of 9.7% in weight is noticed for control mix whereas, 2.5% of reduction of weight is noticed for mix 2, 6.5%of reduction of weight is noticed for mix 4, and 7.2% of reduction of weight is noticed for mix 8. The observed data are shown in the above Table 5.10

5.2.2 SULPHATE ATTACK

Sulphate attack test is done to determine the durability of specimens prepared from different replacements percentages. The concrete cubes of control or conventional mix and remaining mixes are casted and cured for 28 days, their initial weights (dry weight) is noted. Further, the cubes are immediately submerged into the magnesium sulphate solution for 90 days. After 90 days the samples are taken out from the solution and their reduced weights is measured. Similarly the compressive strength is measured for all the specimens.

The curing is performed for control mix and hybrid mixes for 90 days and it is found that, very little thin layer of white precipitate is developed on the outer surface of concrete. The compressive strength is measured for water cured concrete after 28 days and magnesium sulphate solution cured concrete for 90 days.

Table 5.11 Percentage Weight Loss Due to Sulphate Attack Test Results

S.No	Mixes	Compressive Strength after 28 days of normal curing (MPa)	Compressive Strength after 90 days of magnesium sulphate curing (MPa)	Reduction in strength	Reduction in weight
1.	Mix 0	44.3	25	43.56 %	7.5 %
2.	Mix 2	57	52	8.7 %	8.94 %
3.	Mix 4	59	53	10.1 %	9.2 %
4.	Mix 8	60.6	55	9.2 %	4.7 %

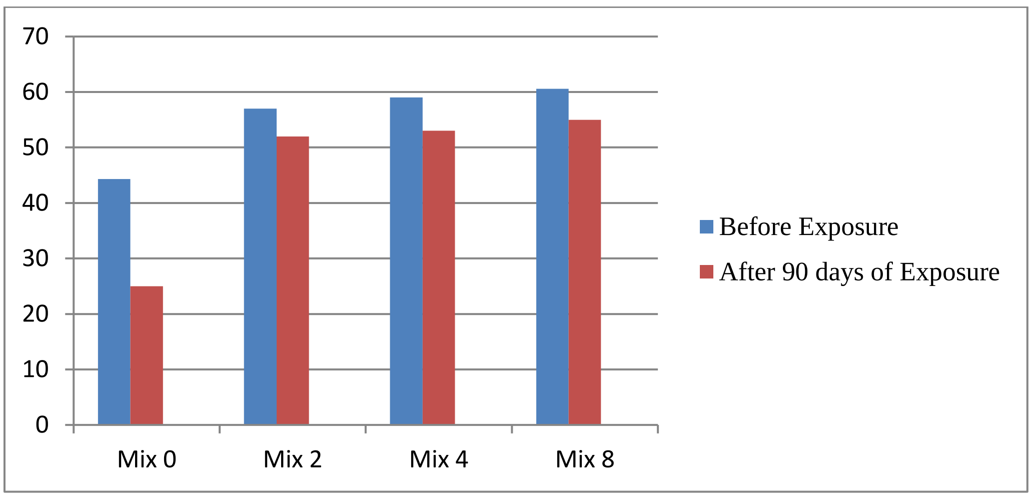


Fig 5.11 Percentage Weight Loss Due to Sulphate Attack Test Results

It is found that the compressive strength for control mix reduces by 43.56%, where as for mix 2 the compressive strength is reduced by 8.7%, for mix 4 the compressive strength is reduced by 10.1%, for mix 8 it is noticed that the reduction is 9.2%. It is observed that a reduction of 7.5% in weight is noticed for control mix whereas, 8.94% of reduction of weight is noticed for mix 2, 9.2%of reduction of weight is noticed for mix 4, and 4.7% of reduction of weight is noticed for mix 8. The observed data are shown in the above Table 5.11.

5.2.3 CHLORIDE ATTACK

Chloride attack test is done to determine the durability of specimens prepared from different replacements percentages. The concrete cubes of control or conventional mix and remaining mixes are casted and cured for 28 days, their initial weights (dry weight) is noted. Further, the cubes are immediately submerged into the sodium chloride solution for 90 days. After 90 days the samples are taken out from the solution and their reduced weights is measured. Similarly the compressive strength is measured for all the specimens.

The curing is performed for control mix and hybrid mixes for 90 days and it is found that, the white precipitate is developed on the outer surface of concrete. The compressive strength is measured for water cured concrete after 28 days and sodium chloride solution cured concrete for 90 days.

Table 5.12 Percentage Weight Loss Due to Chloride Attack test results

S.No	Mixes	Compressive Strength after 28 days of normal curing (MPa)	Compressive Strength after 90 days of Sodium chloride curing (MPa)	Reduction in strength	Reduction in weight
1.	Mix 0	44.3	42	5.19 %	10.39 %
2.	Mix 2	57	55	3.5 %	9.01 %
3.	Mix 4	59	57	3.3 %	14.01 %
4.	Mix 8	60.6	57	5.9 %	12.38 %

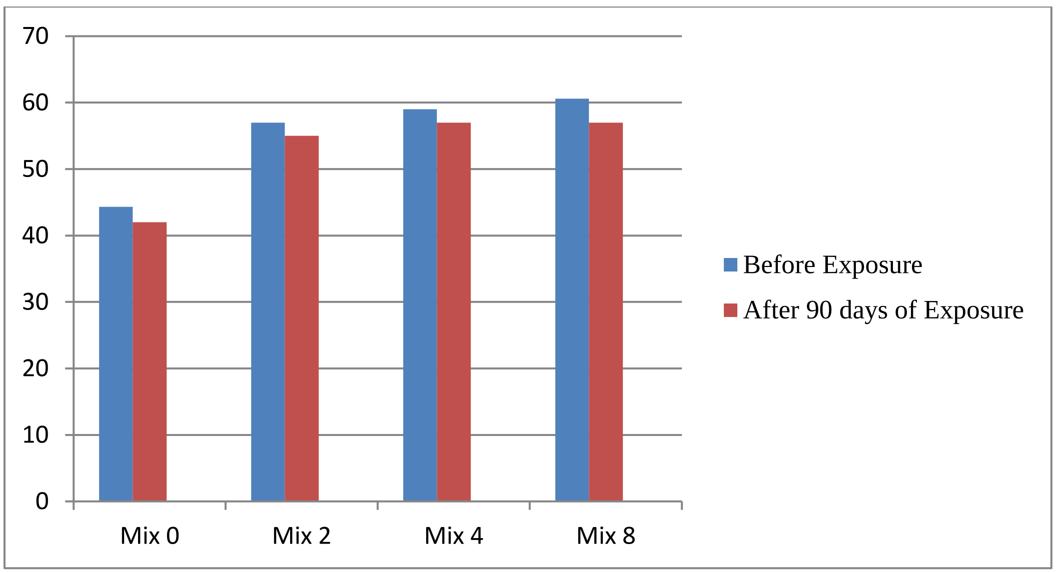


Fig 5.12 Percentage Weight Loss Due to Chloride Attack Test Results

It is found that the compressive strength for control mix reduces by 5.19%, where as for mix 2 the compressive strength is reduced by 3.5%, for mix 4 the compressive strength is reduced by 3.3%, for mix 8 it is noticed that the reduction is 5.9%. It is observed that a reduction of 10.39% in weight is noticed for control mix whereas, 9.01% of reduction of weight is noticed for mix 2, 14.01% of reduction of weight is noticed for mix 4, and 12.38 % of reduction of weight is noticed for mix 8. The observed data are shown in the above Table 5.12.

5.3 MICRO STRUCTURAL INVESTIGATION

Scanning electron microscopy (SEM) test is carried out on the control mix or conventional mix specimens, mix 4 and mix 8. In control mix or conventional mix specimen shown in **Fig 5.13** cracks and pores are visible with heterogeneously distributed unhydrated cement clinkers with unreacted portlandite(CH). These unreacted products are responsible for limited strength of concrete.

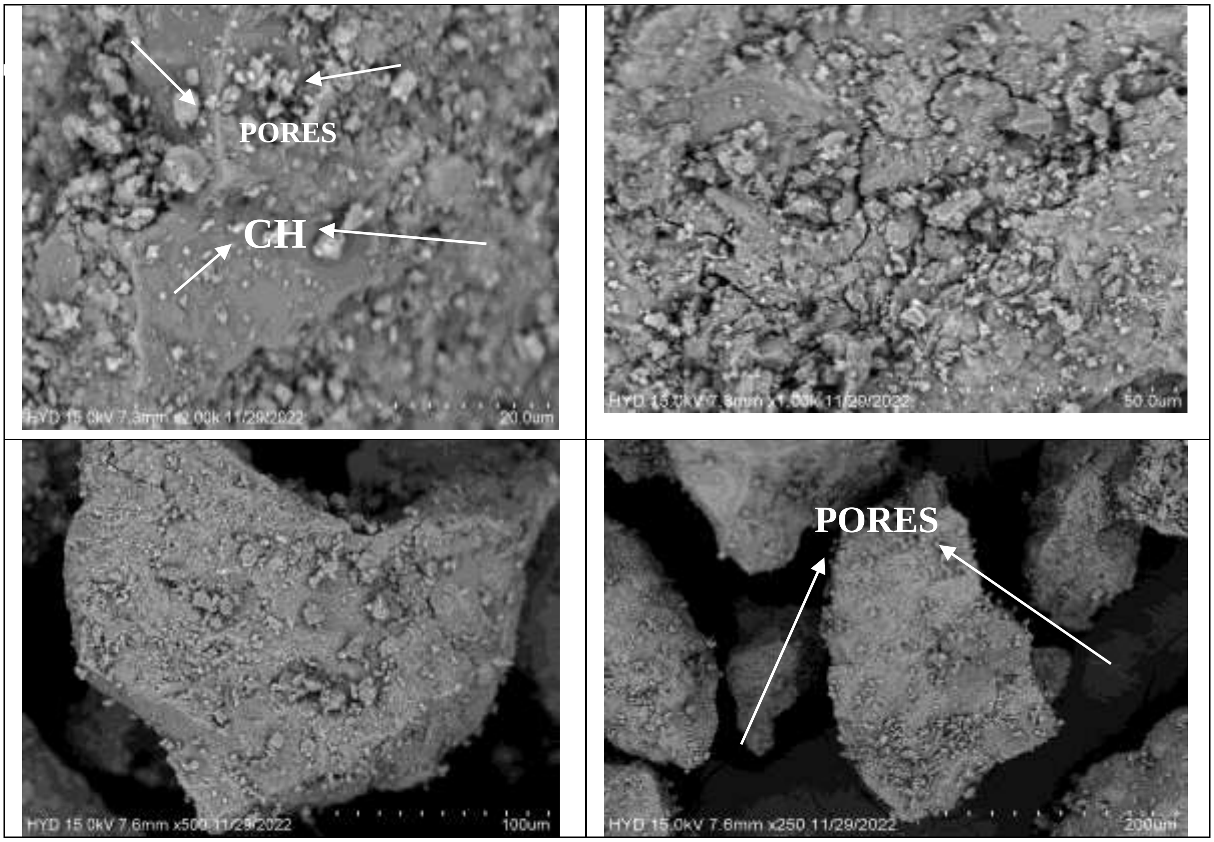
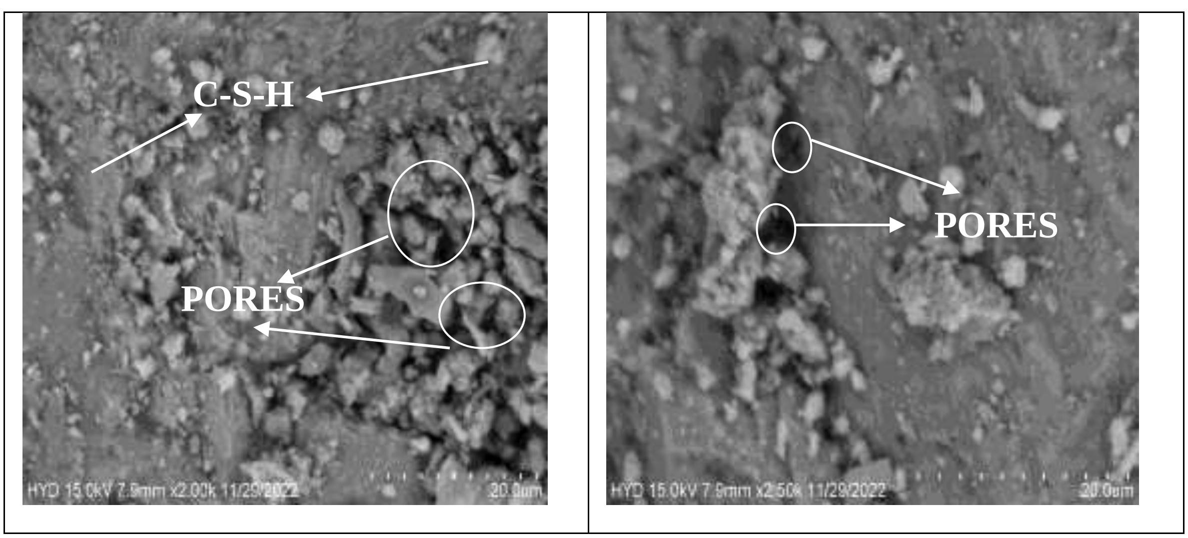


Fig.5.13 Scanning electron microscopy
(SEM) particle image of conventional concrete under 20,50,100 & 200 um

Further in **Fig 5.14** concrete specimen with 2.5% silica fume (SF) and 10% metakaolin(MK) is shown, the presence of Al_2O_3 and SiO_2 in metakaolin helps in development of C-A-S-H gel and presence of SiO_2 in silica fume helps in development of C-S-H gel which enhances the strength of concrete. However some pores are still visible in all the specimens



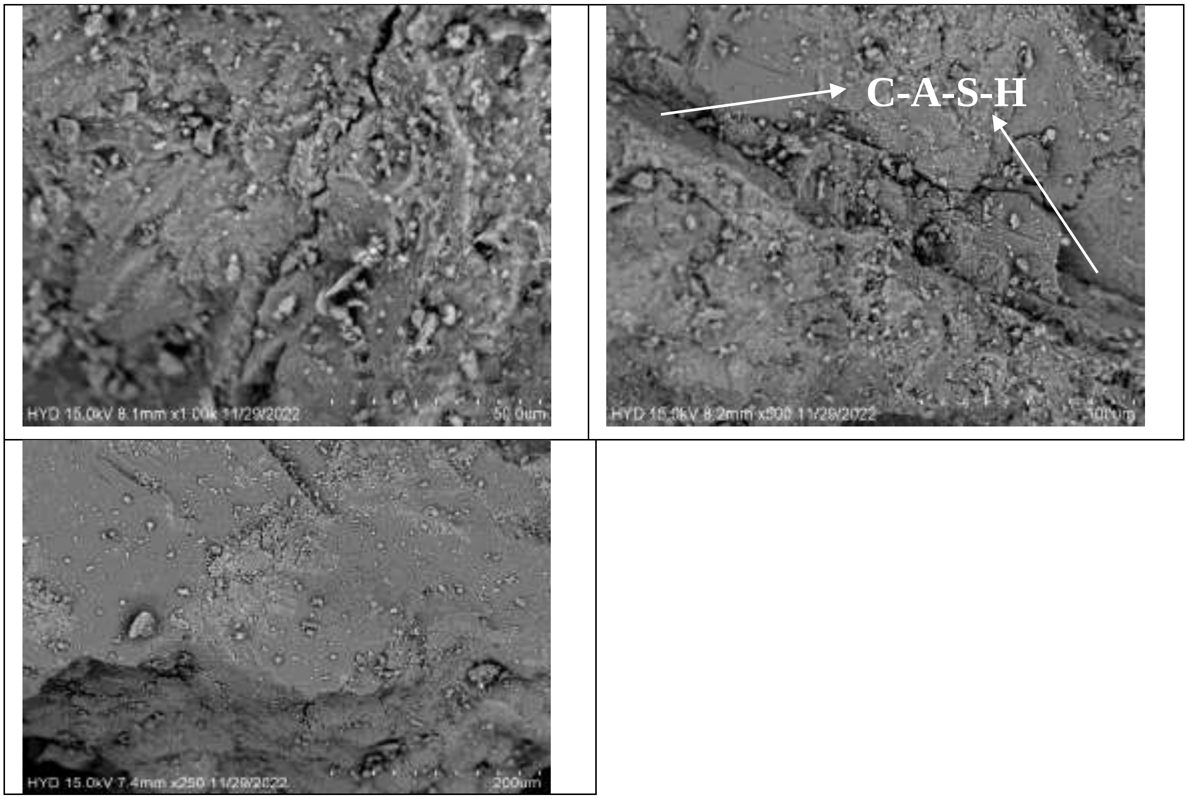
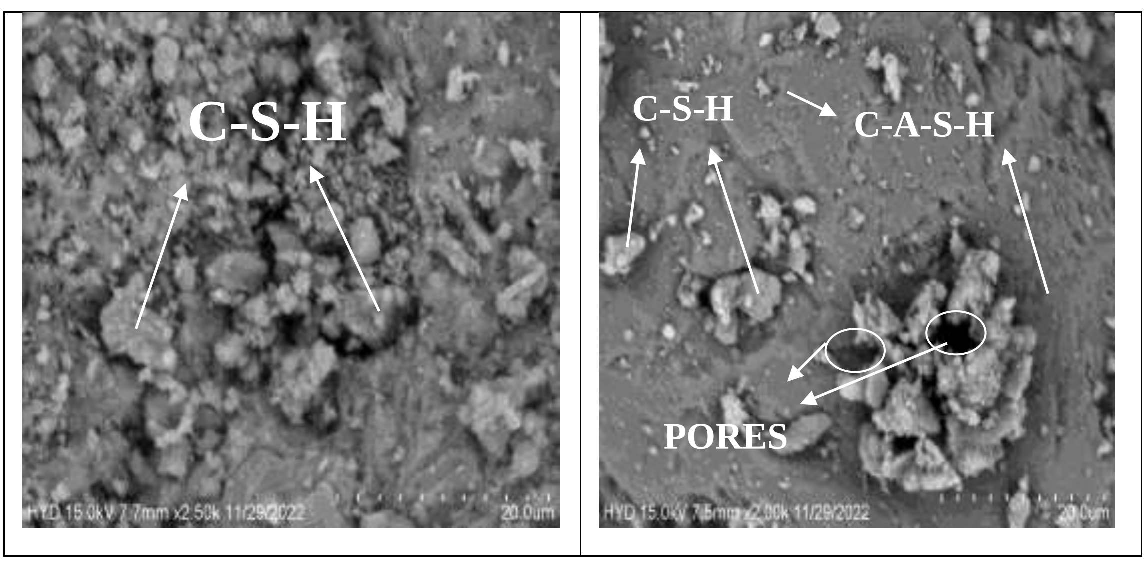


Fig.5.14 Scanning electron microscopy
(SEM) particle image of Mix 4 under 20,50,100 & 200 um

Similarly **Fig 5.15** shows the concrete specimen incorporated with 2.5% silica fume(SF), 10% metakaolin(MK) and 0.8% of basalt fibers. It is evident that a strong and dense microstructure is developed with negligible formation of cracks and pores. A homogeneous distribution of strength imparting hydration produces lilke C-S-H and C-A-S-H gel plays a major role in building the strength of concrete.



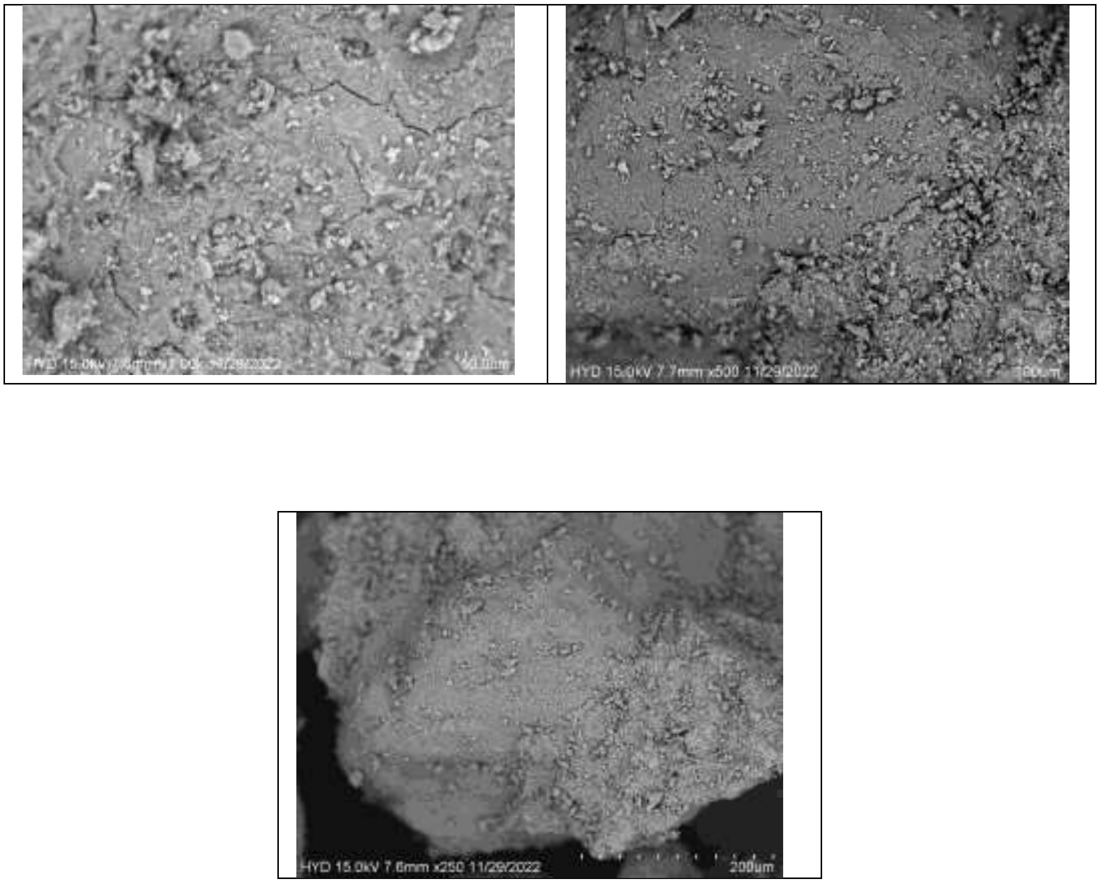


Fig.5.15 The above figures shows the Scanning electron microscopy (SEM) particle image of Mix 8 under 20,50,100 & 200 um

6. CONCLUSIONS

The following conclusions can be drawn from the current study.

a) It was found that MK had a significant effect on the long term compressive strength.
b) Maximum compressive strength is obtained when cement is replaced upto 10% of MK and decreases thereafter.
c) Maximum compressive strength is obtained when 2.5% of silica fume is replaced in cement, when 10% MK is incorporated in conventional concrete.
d) Maximum compressive strength is obtained when 0.8% of basalt fibers is added to the concrete which is 26.89% higher than the conventional concrete.
e) Maximum split tensile strength & flexural strength is obtained when 0.8% Basalt fibers are incorporated.
f) It was also found that MK improved the pore structure of concrete, as indicated by the results obtained from the durability and electron microscopy tests.
g) The samples containing MK displayed a more cohesive matrix, with large extents of C-S-H gels present, which is responsible for preventing the ingress of chloride ions.
h) The presence of Al_2O_3 and SiO_2 in metakaolin helps in development of C-A-S-H gel and presence of SiO_2 in silica fume helps in development of C-S-H gel which enhances the strength of concrete.
i) The hybrid mix (Mix8), when exposed to chloride attack for 90 days which is incorporated with 2.5%SF, 10%MK and 0.8%BF, the compressive strength is reduced by 5.9% only which is 26.8% higher than the conventional mix.

j) The hybrid mix (Mix8), when exposed to sulphate attack for 90 days which is incorporated with 2.5%SF, 10%MK and 0.8%BF, the compressive strength is reduced by 9% only, which is 19.45% higher than the conventional mix.
k) By addition of basalt fibers the tensile strength is increased and it can reduce the cracks and increase the impact resistance.
l) Incorporation of fibers improves the fracture toughness parameters of concrete.

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