Experimental Study on Effect of Different Types of Mineral Admixture Used as supplement of cement along with Exfoliated vermiculite as substitute to Fine aggregate

M.Preethi[1], Dr. Mohd. Hamraj[2] Dr. N. Suresh Kumar [3]

1. Associate Professor, Deccan College of Engineering and Technology, Hyderabad. Mail id: -preethi.sreeraag@gmail.com
2. Professor, H.O. D, Department of Civil Engineering in Muffakham Jah college of Engineering and Technology,Hyderabad. Mail id: - hamraj@mjcollege.ac.in
3. Professor, College of Engineering Osmania University, Hyderabad. Mail id:-nskdr@yahoo.co.in

Abstract

Exfoliated vermiculite is inventive equivalent to fine aggregate generating towards unique light weight concrete with rise in characteristics of concrete when converged with traditional concrete, in this research analysis M30 grade contrasting form of concrete samples have been composed. Exfoliated Vermiculite is adapted as replacement to fine aggregate along with various admixtures of mineral being Fly ash, dolomite, silica fume, ground granulated blast furnace slag, and Metakaolin as a fractional replacement for cement. Research has been done on the concrete's mechanical aspects. According to this study, replacing five to ten percent of fine aggregate with vermiculite improved the strength of all admixtures. All of the properties have enhance when 10% silica fume is used to replace cement; 10% Metakolin and 40% GGBS has shown greater compressive strength, and 30% dolomite has not shown any effect. The target strength was reached by replacing 20% of the cement with fly ash and 10% of the fine aggregate with vermiculite.

Keywords Dolomite, Metakaolin, Fly ash, Vermiculite, Lightweight Concrete, Cement, Silica Fume, Ground Granulated Blast Furnace Slag (GGBS), Fine Aggregate.

1. Introduction

Modern society is largely composed of concrete buildings. There really is currently no worthy alternative to concrete as a structural material. The construction sector significantly reduces natural resource reserves, especially those of aggregates, which make up the majority of concrete volume, as a result of the large-scale production of concrete. In a society that is becoming more environmentally aware, another element that is made responsible for climate change and having a negative effect on the environment is the production of concrete. [1]

Concrete, the most used building material, is primarily made of binding material and natural aggregates. Ordinary Portland cement (OPC) is a primary binder utilized in the creation of concrete [2]. About one tonne of carbon dioxide is estimated to be discharged into the atmosphere as a result of producing one tonne of OPC, harming the environment. [3]. The fine aggregate ingredient of concrete has been traditionally made of river sand, which has caused in an over use of this non-renewable natural resource. The excess use of sand from river results in a negatively affecting the ecosystem's environment. Identifying suitable substitutes for natural sand and OPC in the manufacturing of concrete is crucial as a result.

Waste materials can successfully replace natural aggregate. Sintered fly ash (SFA) is an example of such a product. Fossil fuel burning produces fly ash as a by-product. The amount of fly ash utilized by the cement industry in India during the 2018–19 calendar year is around 60.11 million tonnes. Apart from the cost savings, using fly ash in Portland cement results in a significant decrease in bleeding, shrinkage, and heat of hydration as well as an improvement in workability, durability, and ultimate strength. Because of the issues with the quantity of space needed for safe disposal and the adverse effects on the environment, fly ash production is problematic. Currently, 77.59 percent of all fly ash produced in India is used in different sectors. However, the focus should be on 100% usage while taking into account the mentioned possible uses of fly ash in the industrial, agricultural, and building sectors [4].

When heated, this micaceous mineral vermiculite exfoliates to create a very porous, low-density aggregate. [5]. Vermiculite is produced throughout the world in an estimated 2.35 million tonnes, according to reports. The United States, Australia, South Africa, China, Russia, India, and Uganda are major vermiculite producers. [6]. When vermiculite is heated from 650^{o} C to 1000°C, it develops to 8-30 times its real quantity [7]. For that reason, the vermiculite in expanded form shows high sound insulation, low density, low thermal conductivity and high refractoriness [8] The production of carbon dioxide emissions during vermiculite expansion also has not been researched. [9]. Because of its light weight, heat insulation, and sound absorption characteristics, concrete of light weight is produced with aggregate made of expanded vermiculite. [10].

Regardless of the fact that the usage of lightweight concrete all the time growing its practical environmental benefits, economic. Many engineers, architects, and builders still find it to be a difficult technological and regulatory problem. Conforming to the ACI guidelines for Structural Lightweight Concrete, it may produce if its density ranges from “320 to 1920 kg/m3” (ACI 213, 2001). Due to its light weight, SFA (sintered fly ash) is used as lightweight structural concrete. SFA concrete has a density of 1450 kg/m3. The research programme therefore concentrated on testing the compatibility of two different light weight aggregates in a single concrete. The study's main innovation is the simultaneous use of two different types of lightweight aggregates. They can be combined in different ratio to produce a very broad range of mechanical effects. Such a technique offers new kinds of lightweight concretes and is innovative.

1.1 Research Significance

Abundant scholarly papers are accessible on light weight concrete using different admixtures but utilization of Exfoliated vermiculite as sand substitute only few studies have been done which directed for further study to determine best suitable admixture for contrasting variation of exfoliated vermiculite for design mix of M30 grade considering mechanical strength parameters for comparison.

2.Experimental Procedure

2.1 Materials

The materials used in this research include.

Cement: Ultra tech Cement of grade 53 was used for composition of concrete mix.
Sand (Fine aggregate): Aggregate Fines Commercially accessible yellow sand was used as fine aggregate in the manufacture of the concrete mix. According to IS: 10262-2019 [14] requirements, the sand is of Grade II
Coarse aggregate: angular crushed stone, available for purchase the design of the concrete mix was based on the nominal size and proportion of coarse particles that were passing through 20 mm and retained on 10 mm sieve.
Silica fume: A by-product of the manufacturing of silicon metal and Ferro-silicon amalgam is fume of the silica range. The process involves reducing high purity quartz (SiO_2) at temperatures greater than 2,000 °C in electric circular segment heaters. A fine powder known as silica range has a huge specific surface area (15,000–25,000 m2/kg) and is predominantly composed of round particles or microspheres with a mean diameter of 0.15 microns.
Metakaolin: Metakaolin is an amorphous aluminosilicate that is reactive in concrete and is created by burning (calcining) refined kaolin clay under controlled conditions. Like other pozzolans, such as fly ash and silica fume, Metakaolin reacts with the calcium hydroxide (lime) waste products created during cement hydration. Metakaolin (MK) can be used successfully to partially substitute cement in paste, mortar, and concrete applications. Metakaolin is made by calcining kaolin clay at temperatures ranging between 700 and 900°C. The major oxides in the MK, like clay, are silica and alumina. Cement-based products' mechanical and durability qualities can be enhanced by partially substituting MK for cement.
Fly ash: A heterogeneous byproduct of the combustion of coal in power plants is a material known as fly ash. It is a thin, grey powder that rises with flue gases and contains glassy, spherical particles. due to the pozzolanic elements included in fly ash, which interact with lime to produce cementing materials.

Water: Water is an essential component of concrete, and it chemically reacts with cement. The water used in concrete should be devoid of acid, dust, and other impurities. The PH value should be between 6 and 8.

Dolomite: Dolomite powder is a type of calcium magnesium carbonate that occurs naturally. It can be found all throughout the world and is particularly common in sedimentary rock formations. These rocks are suitably referred to as dolomite or dolomite limestone. It is a superior construction material due to its higher hardness. Its reduced solubility makes it more resistant to the acid content of rain and soil.

Vermiculite: Vermiculite is a phyllosilicate mineral. A lower density for the same strength level reduces self-weight. It has a high silica concentration, which gives it a strong constraint for substituting sand and is effective for bonding and covering voids. It is generally platelets with diameters ranging from 0.04 to 4mm.

Ground Granulated Blast Furnace Slag (GGBS):

Blast-furnace iron manufacturing generates GGBF as a byproduct. Mostly silicate and aluminosilicate of molten calcium make up this substance. Similar to fly ash, the raw materials used in the production of iron determine the chemical compositions of GGBFS, whereas the physical characteristics are determined by using molten materials to create amorphous glassy granulated particles or pelletizing it with a combination of water jet and air to create spherical glassy pellets of various sizes, smaller than one nanometer in size.

2.2 Specimen Fabrication

Design Concrete mix of grade M30 asserting to IS: 10262-2019 [14] and SP 23 [12] was adopted for the formation of test specimens. The fraction of various elements of the concrete mix are given below

The cement: fine aggregate: coarse aggregate and water ratio are estimated at 1:1.42:1.66:0.4

2.3 Testing Procedure

Total 36 concrete mixes have been casted each mix. has nine cubes of 100x100x100 mm tested for seven, fourteen and twenty-eight days' compressive strength as per IS: 516 [11], 100x100x500 mm prism tested for flexure as per IS 516 [11] and 150mmdiameter with300mm height cylinder for split tensile strength as per IS 5816 [15] [13] for different proportions of cement replaced with mineral admixtures along with fine aggregates replaced with variation of 0,5,10,15,20, and 25% replacement of fine aggregate with vermiculite. The findings were graphed, and then comparative analysis graphs were made to indicate the effect of various mineral admixtures on the flexural strength and split tensile strength for 28 days, and compressive strength of concrete at 7, 14, and 28 days.

Figure-1 Materials, Specimen and Testing

Table 1: Mix proportions

Con.mix samples	Cement (kg)	% Admixture	Admixture (kg)	FA (kg)	Vermiculite (kg)	CA(kg)	Water (L)	w/c ratio
A_1	28.23	0	0	40.08	0	46.86	11.29	0.4
A_2	28.23	0	0	38.08	2	46.86	11.29	0.4
A_3	28.23	0	0	36.08	4	46.86	11.29	0.4
A_4	28.23	0	0	34.08	6	46.86	11.29	0.4
A_5	28.23	0	0	32.08	8	46.86	11.29	0.4
A_6	28.23	0	0	30.08	10	46.86	11.29	0.4
A_7	25.41(10%)	10%	SF 2.82	40.08	0	46.86	11.29	0.4
A_8	25.41(10%)	10%	SF 2.82	38.08	2	46.86	11.29	0.4
A_9	25.41(10%)	10%	SF 2.82	36.08	4	46.86	11.29	0.4
A10	25.41(10%)	10%	SF 2.82	34.08	6	46.86	11.29	0.4
A_{11}	25.41(10%)	10%	SF 2.82	32.08	8	46.86	11.29	0.4
A_{12}	25.41(10%)	10%	SF 2.82	30.08	10	46.86	11.29	0.4
A_{13}	25.41(10%)	10%	MT2.82	40.08	0	46.86	11.29	0.4
A_{14}	25.41(10%)	10%	MT2.82	38.08	2	46.86	11.29	0.4
A_{15}	25.41(10%)	10%	MT2.82	36.08	4	46.86	11.29	0.4
A_{16}	25.41(10%)	10%	MT2.82	34.08	6	46.86	11.29	0.4
A_{17}	25.41(10%)	10%	MT2.82	32.08	8	46.86	11.29	0.4
A_{18}	25.41(10%)	10%	MT2.82	30.08	10	46.86	11.29	0.4
A_{19}	22.58(20%)	20%	FA4.65	40.08	0	46.86	11.29	0.4
A_{20}	22.58(20%)	20%	FA4.65	38.08	2	46.86	11.29	0.4
A_{21}	22.58(20%)	20%	FA4.65	36.08	4	46.86	11.29	0.4
A_{22}	22.58(20%)	20%	FA4.65	34.08	6	46.86	11.29	0.4
A_{23}	22.58(20%)	20%	FA4.65	32.08	8	46.86	11.29	0.4
A_{24}	22.58(20%)	20%	FA4.65	30.08	10	46.86	11.29	0.4
A_{25}	16.93(40%)	40%	GG11.3	40.08	0	46.86	11.29	0.4
A_{26}	16.93(40%)	40%	GG11.3	38.08	2	46.86	11.29	0.4
A_{27}	16.93(40%)	40%	GG11.3	36.08	4	46.86	11.29	0.4
A_{28}	16.93(40%)	40%	GG11.3	34.08	6	46.86	11.29	0.4
A_{29}	16.93(40%)	40%	GG11.3	32.08	8	46.86	11.29	0.4
A_{30}	16.93(40%)	40%	GG11.3	30.08	10	46.86	11.29	0.4
A_{31}	19.76(30%)	30%	D8.47	40.08	0	46.86	11.29	0.4
A_{32}	19.76(30%)	30%	D8.47	38.08	2	46.86	11.29	0.4
A_{33}	19.76(30%)	30%	D8.47	36.08	4	46.86	11.29	0.4
A_{34}	19.76(30%)	30%	D8.47	34.08	6	46.86	11.29	0.4
A_{35}	19.76(30%)	30%	D8.47	32.08	8	46.86	11.29	0.4
A_{36}	19.76(30%)	30%	D8.47	30.08	10	46.86	11.29	0.4

The composition of samples with compressive strength, split tensile strength, flexural strength and weight of each mix. As shown in Table 2

Table 2: Test results

S.NO	CON. MIX	CS 7 Days (MPa)	CS 14 Days (MPa)	Cube WT 28 Days (kg)	CS 28 Days (MPa)	SPT 28 Days (MPa)	FS 28 Days (MPa)
A1	$0VM_1$	31.68	42.02	2.43	45.55	2.62	4.98
A2	$5VM_2$	30.69	40.15	2.39	43.80	2.41	4.73
A3	$10VM_3$	28.48	38.53	2.32	41.13	2.29	4.49
A4	$15VM_4$	26.83	36.53	2.26	39.18	2.07	4.32
A5	$20VM_5$	20.08	21.43	2.20	23.11	1.78	3.48
A6	25VM6	11.23	13.22	2.09	14.46	1.26	2.95
A7	$0VM_7$ SF	34.50	36.50	2.29	50.33	3.11	5.82
A8	$5VM_8$SF	32.00	33.75	2.26	46.33	2.71	5.21
A9	$10VM_9$SF	22.00	24.50	2.21	35.66	2.42	4.27
A10	$15VM_{10}$SF	19.50	22.25	2.17	27.18	2.19	3.86
A11	$20VM_{11}$SF	14.00	19.60	2.15	21.25	1.82	3.38
A12	$25VM_{12}$SF	10.00	12.75	2.12	13.18	1.47	2.85
A13	$0VM_{13}$MT	34.70	49.20	2.30	53.93	3.00	6.19
A14	$5VM_{14}$MT	33.13	47.10	2.29	51.63	2.78	6.01
A15	$10VM_{15}$MT	30.83	44.76	2.18	48.70	2.57	5.54
A16	$15VM_{16}$MT	27.87	38.43	2.06	41.03	2.33	4.67
A17	$20VM_{17}$MT	25.53	35.50	1.88	38.30	1.93	2.8
A18	$25VM_{18}$MT	21.23	28.06	1.61	33.46	1.52	1.33
A19	$0VM_{19}$FA	29.46	39.93	2.29	44.63	4.72	5.6
A20	$5VM_{20}$FA	28.80	38.40	2.26	42.90	4.36	5.07
A21	$10VM_{21}$FA	26.73	36.80	2.11	40.23	4.05	4.93
A22	$15VM_{22}$FA	25.03	33.56	1.99	38.30	3.43	4.72
A23	$20VM_{23}$FA	19.36	30.06	1.80	34.96	2.75	3.67
A24	$25VM_{24}$FA	17.43	26.63	1.60	31.03	1.69	3.20
A25	$0VM_{25}$GG	29.80	36.80	2.68	43.33	4.11	5.42
A26	$5VM_{26}$GG	28.12	35.80	2.40	40.66	3.57	5.33
A27	$10VM_{27}$GG	27.60	34.30	2.20	38.70	2.97	5.02
A28	$15VM_{28}$GG	25.40	30.12	2.11	36.33	2.08	4.88
A29	$20VM_{29}$GG	20.12	27.00	1.98	29.80	1.16	4.73
A30	$25VM_{30}$GG	18.16	24.95	1.85	26.14	0.79	4.29
A31	$0VM_{31}$D	20.66	36.20	2.53	38.36	3.75	4.86
A32	$5VM_{32}$D	20.15	35.66	2.44	37.55	3.48	4.73
A33	$10VM_{33}$D	19.46	35.36	2.30	35.25	2.92	4.52
A34	$15VM_{34}$D	16.06	21.01	2.09	34.06	2.51	4.13
A35	$20VM_{35}$D	14.03	17.95	1.96	26.76	1.75	3.94
A36	$25VM_{36}$D	08.08	09.18	1.84	18.65	1.34	2.73

Sample nomenclature.

Where A1, A7, A13, A19, A25 and A31 represents samples for 0% vermiculite
Where A2, A8, A14, A20, A26 and A32 represents samples for 5% vermiculite
Where A3, A9, A15, A21, A27 and A33 represents samples for 10% vermiculite
Where A4, A10, A16, A22, A28 and A34 represents samples for 15% vermiculite
Where A5, A11, A17, A23, A29 and A35 represents samples for 20% vermiculite
Where A6, A12, A18, A24, A30 and A36 represents samples for 25% vermiculite
A1, A2, A3, A4, A5 and A6 represents samples without any admixture.
A7, A8, A9, A10, A11 and A12 represents samples with silica fume as replacement to cement.
A13, A14, A15, A16, A17 and A18 represents samples with Metakaolin as replacement to cement
A19, A20, A21, A22, A23 and A24 represents samples with fly ash as replacement to cement
A25, A26, A27, A28, A29 and A30 represents samples with GGBS as replacement to cement
A31, A32, A33, A34, A35 and A36 represents samples with dolomite as replacement to cement

3.Experimental Results and Discussions

3.1. Weights

Weight of all the 36 samples (108 cubes) of 28 days have taken. Normal concrete with 25% vermiculite replacement loses 14% of its weight, while 10% vermiculite replacement loses only 4% of its weight. The weight reduction with 10% silica fume and 10% vermiculite is 3.5%, and the weight reduction with normal mix is 9%. Metakaolin decreases vermiculite by 30% and 25% decreases vermiculite by 5%. Fly ash of 20% with 25% vermiculite reduced by 30.1% as seen, and 7.9% with 10% vermiculite. GGBS of 40% and 10% vermiculite reduced weight by 18%, while normal concrete reduced weight by only 9.3%. Dolomite (30% and 10% vermiculite) resulted in a 9.2% decrease [Figure-2].

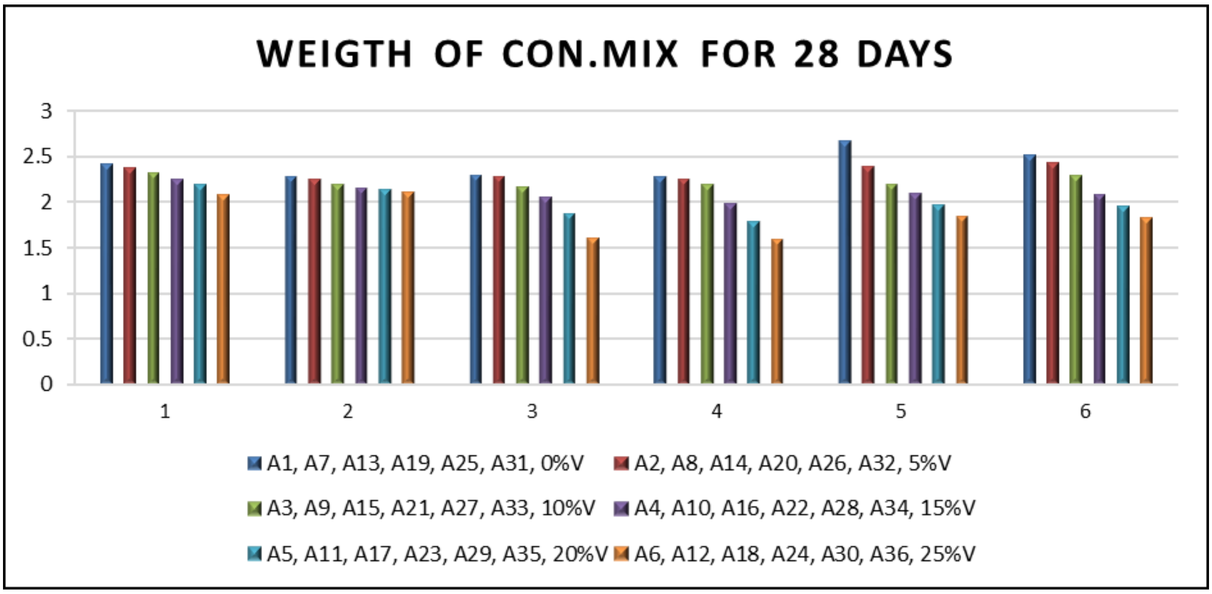


Figure- 2: Weight for 28 days comparison of mineral admixture s for varying proportions of vermiculite

Series of 1, 2,3,4,5 and 6 along x – axis indicates 0% of vermiculite, 5% of vermiculite, 10% of vermiculite, 15% of vermiculite, 20% of vermiculite and 25% of vermiculite along y-axis weight

3.2. Compressive Strength

Compressive Strength was done for 7, 14 and 28 days for all 36 mixes (324 cubes). When Metakaolin was added to cement at all ages and percentages of vermiculite, the results were superior to normal concrete. Similarly, the addition of GGBS and fly ash produced very good results for all of the mixes, whereas Dolomite and Silica fume addition produced good results [Figures-3,4 & 5]. When 10% vermiculite was added to all of the mixes, Metakaolin produced 45% more strength, Fly ash 33.3% more strength, GGBS 30.67% more strength, Silica fume 25% more strength, and Dolomite 23.89% more strength when compared to the standard mix. Figure-8 depicts a relationship between vermiculite percentages and compressive strength. 'Y' represents compressive strength, and 'X' represents various vermiculite percentages. The curve is linear for all mixes, including normal mix, but square parabolic for Dolomite.

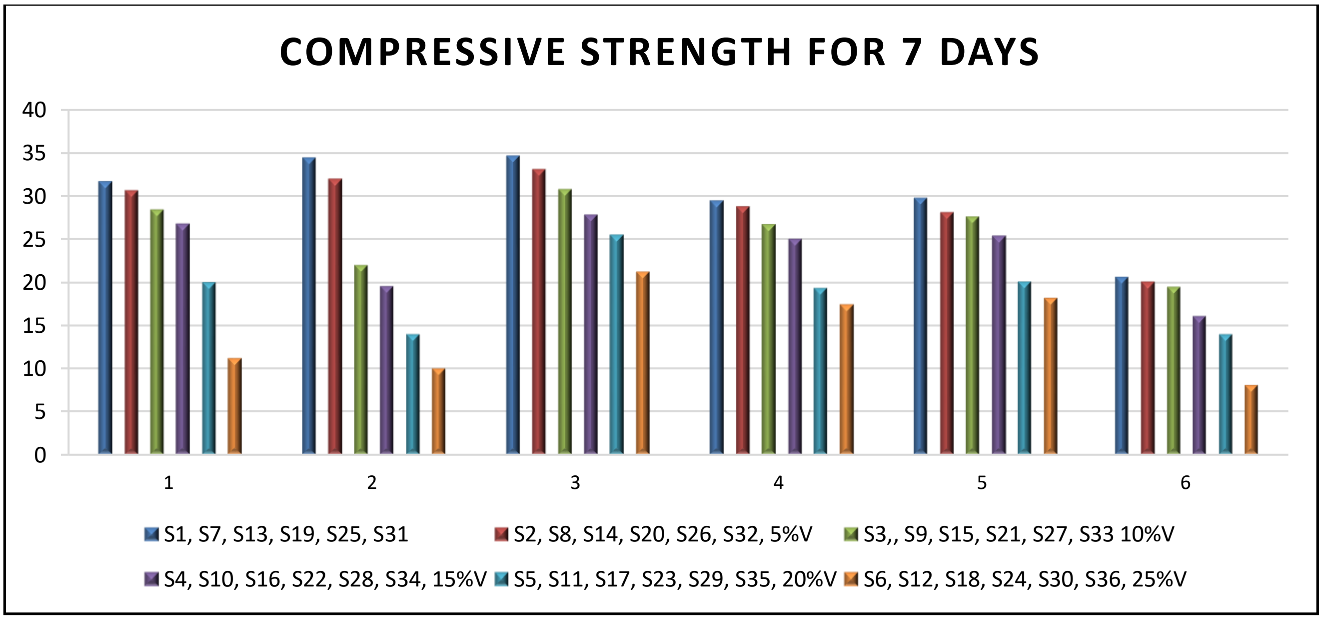


Figure- 3: CS for 7 days' comparison of mineral admixtures for varying proportions of vermiculite.

Series of 1, 2,3,4,5 and 6 along x – axis indicates 0% of vermiculite, 5% of vermiculite, 10% of vermiculite, 15% of vermiculite, 20% of vermiculite and 25% of vermiculite, along y-axis compressive strength

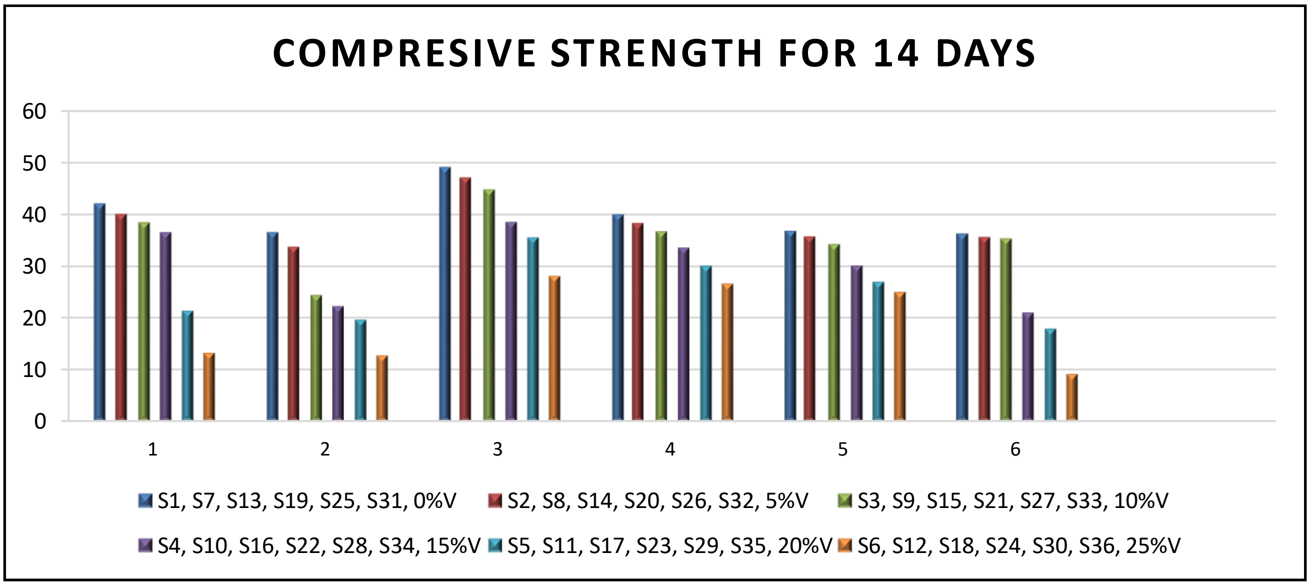


Figure- 4: CS for 14 days comparison of mineral admixture s for varying proportions of vermiculite

Series of 1, 2,3,4,5 and 6 along x – axis indicates 0% of vermiculite, 5% of vermiculite, 10% of vermiculite, 15% of vermiculite, 20% of vermiculite and 25% of vermiculite, along y-axis compressive strength

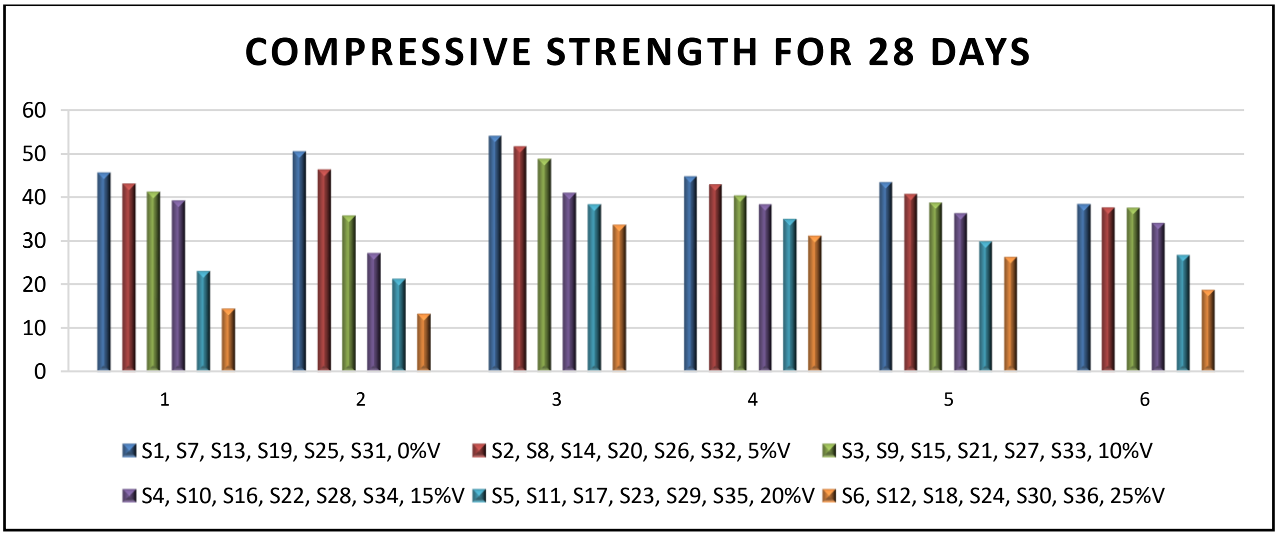
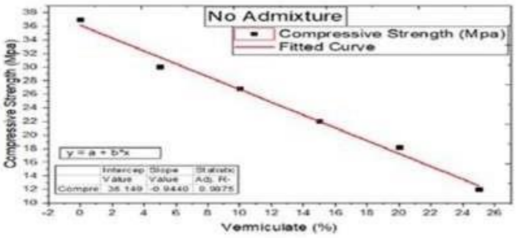
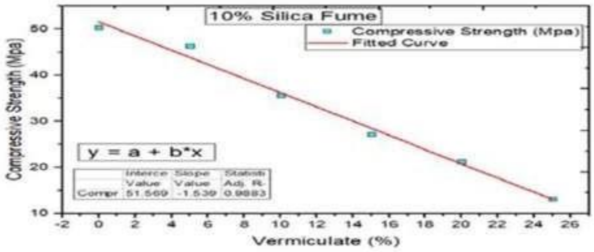


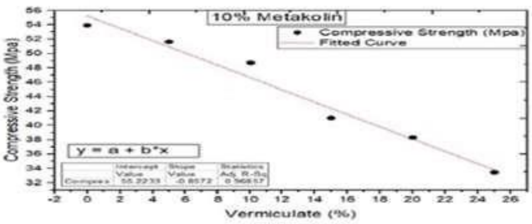
Figure- 5: CS for 28 days comparison of mineral admixture s for varying proportions of vermiculite. Series of 1, 2,3,4,5 and 6 along x – axis indicates 0% of vermiculite, 5% of vermiculite, 10% of vermiculite, 15% of vermiculite, 20% of vermiculite and 25% of vermiculite, along y-axis compressive strength



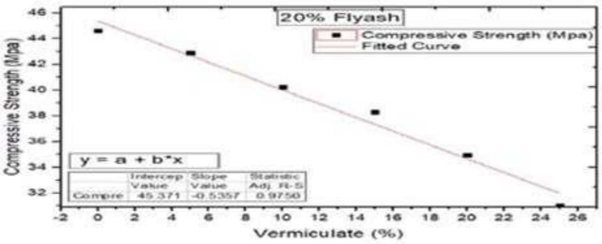
Y = 36.149+(-0.9440) X



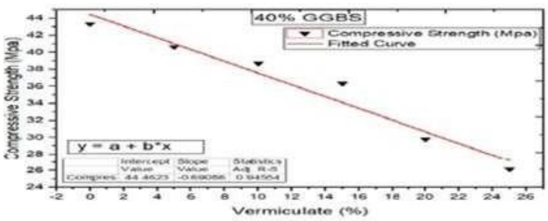
Y= 51.569+(-1.539) X



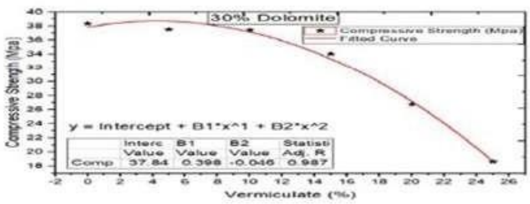
Y = 55.2233+(-0.8572) X



Y = 45.371+(-0.5357) X



Y = 44.4623+(-0.69086) X



Y= 37.84+(0.3980) X+(-0.046) X^2

Figure-6: Equations between Percentage of Vermiculite Vs Compressive Strength for various admixtures, along x-axis percentage of vermiculite and y-axis compressive strength.

3.3. Split Tensile and Flexural Strength

Split tensile strength and Flexural strength was done for all the mixes at 28 days (108 cylinders, 108 prisms). Fly ash performed well in split tensile strength and silica fume accomplished well in flexural strength. In terms of split tensile strength, all admixture additions produced good results when compared to the control mix specially for 15 and 20% vermiculite, whereas in flexure, addition for 5% vermiculite has given effective results [Figures-7 & 8].

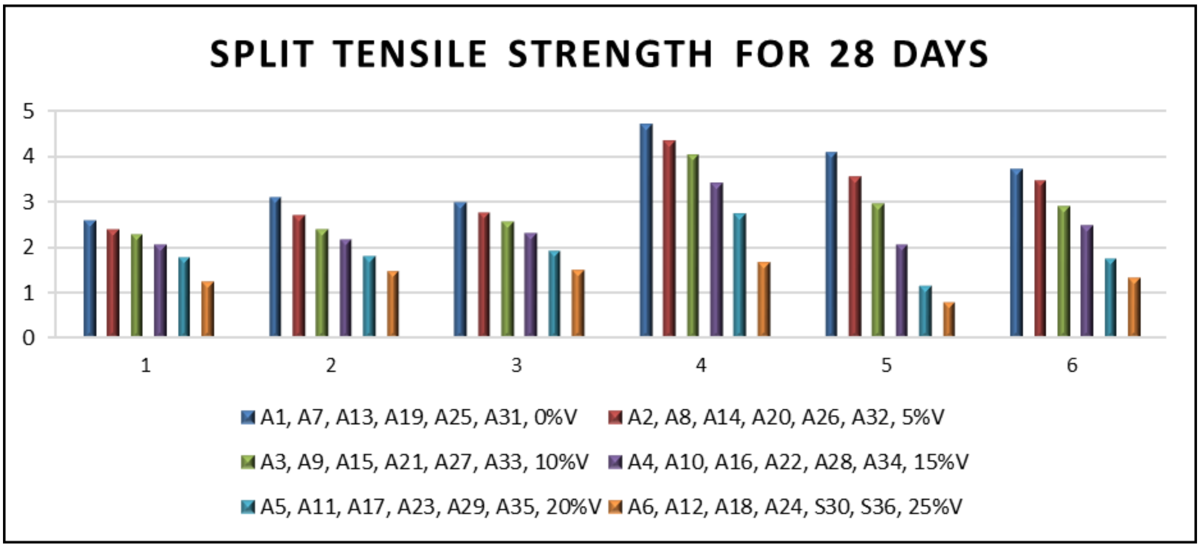


Figure-7: Split tensile strength for 28 days comparison of mineral admixture s for varying proportions of vermiculite.

Series of 1, 2,3,4,5 and 6 along x – axis indicates 0% of vermiculite, 5% of vermiculite, 10% of vermiculite, 15% of vermiculite, 20% of vermiculite and 25% of vermiculite.

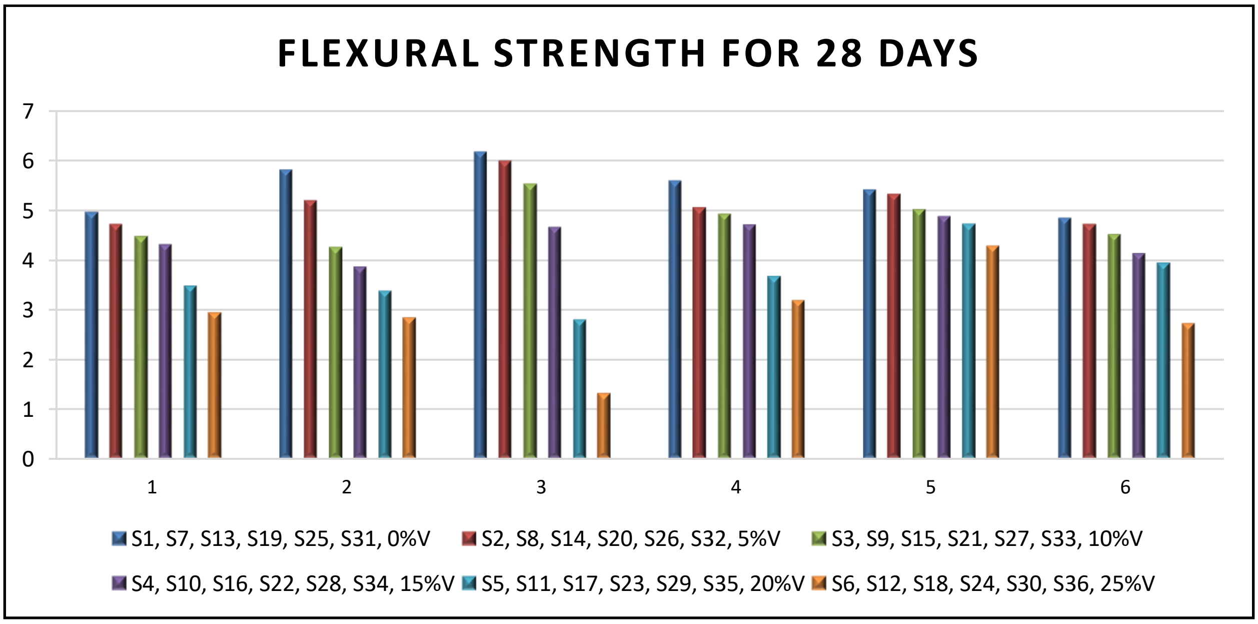


Figure-8: Flexural strength for 28 days comparison of mineral admixture s for varying proportions of vermiculite.

Series of 1, 2,3,4,5 and 6 along x – axis indicates 0% of vermiculite, 5% of vermiculite, 10% of vermiculite, 15% of vermiculite, 20% of vermiculite and 25% of vermiculite

5. Conclusion

- Weight with replacement of vermiculite up to 10% has shown 5 to 10% reduction in weight for all the admixtures, whereas for 25% replacement up to 30%. The strengths have been reduced by the additional percentage increase in vermiculite for fine aggregate
- M30 grade has a stronger strength with 10% replacement of vermiculite with fine aggregate and 10% silica fume with cement, but when it comes to compressive strength, Metakaolin with 10% and 40% GGBS are the best, while adding fly ash with 20% achieves the target strength, whereas Dolomite with a 30% content had no noticeable impact.
- For compressive strength of fourteen days when ten percent of vermiculite is adopted as replacement to Fine aggregate along with replacement of cement with all admixtures except dolomite had given good strength appreciably.
- Concrete mix with GGBS, dolomite, and silica fume replacement to cement along fifteen, twenty and twenty-five percent replacement of fine aggregate with vermiculite had reduced the strength parameters when compared to concrete with fly ash and Metakaolin.
- Replacement of five, ten percent of vermiculite to fine aggregate had given good strength for all admixtures.
- In terms of split tensile strength, fly ash performed well, while silica fume performed well in terms of flexural strength. When compared to the control mix, all admixture additions produced good results in terms of split tensile strength, whereas 5% addition of vermiculite has produced effective results in terms of flexural strength.

6.References

1. Van Damme, H. 2018 Concrete material science: Past, present, and future innovations. Cem. Concr. Res., 112, pp. 5–24
2. Farinha et al 2019 "Influence of forest biomass bottom ashes on the fresh, water and mechanical behaviour of cement-based mortars". Resour. Conserv. Recycl. 2019, 149, pp. 750–759.
3. Mehta, P.K.; Monteiro, P.J.M. Concrete Microstructure, Properties and Materials; McGraw Hill Professional: New York, NY, USA, 201.
4. Aadil Yousuf et al 2020 "Fly Ash: Production and Utilization in India - An Overview" J. Mater. Environ. Sci., 2020, Volume 11, Issue 6, pp. 911-921.
5. Richard Shield et al 1962 "Shock mitigation with lightweight vermiculite concrete" the university of texas structural mechanics research laboratory Austin, Texas February
6. Government of India MoM. 2019. "Part-III: Mineral Reviews."
7. Hwang, Chao-Lung, and Meng-Feng Hung. 2005. "Durability Design and Performance of Self-Consolidating Lightweight Concrete." Construction and Building Materials 19(8):619–26.
8. Melo et al 2012. "Energy Efficiency in Building Installations Using Thermal Insulating Materials in Northeast Brazil." Energy and Buildings 47 pp. 35–43.
9. Epa U. 1995. AP-42: Compilation of Air Emissions Factors. Research Triangle Park NC: US Environmental Protection Agency.
10. Shubbar et al 2020. "The Development of a New Low Carbon Binder for Construction as an Alternative to Cement." pp. 205–13 in Advances in Sustainable Construction Materials and Geotechnical Engineering. Springer.
11. Bureau of Indian Standards. (1959). Indian standard methods of tests for strength of concrete IS: 516-1959, (Reaffirmed 1999), New Delhi, India.
12. Bureau of Indian Standards. (1982). Handbook on concrete mixes (Based on Indian Standards) SP: 23-1982, New Delhi, India.
13. Bureau of Indian Standards. (2000). Indian standard plain and reinforced concrete - code of practice IS: 456-2000, (Reafflrmed 2005), New Delhi, India.

14. Bureau of Indian Standards. (2019). Indian standard concrete mix proportioning - guidelines (IS: 10262-2019), New Delhi, India.
15. Bureau of Indian Standards. (1959). Indian standard Method of test for split tensile strength - guidelines IS: 5816-1959, (Reaffirmed 1999), New Delhi, India.