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Sulphate and chloride resistance of vermiculite blended concrete

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Abstract: In the construction industry lot of natural sand is being used in the preparation of concrete. Levels of natural sand are depleting day by day. The cost of natural sand is also increasing every day. Therefore, there is a need for alternative materials to natural sand. In this study, exfoliated vermiculite is replacing natural sand partially. Vermiculite at 5%, 10%, and 15% is used for replacement. The concrete cubes are cast for M 30 grade to determine the optimal percentage of replacement of natural sand by vermiculite. In this study, coarse aggregate used includes both normal aggregate and recycled aggregate. The water-cement ratio of 0.45 is adopted. The durability tests conducted include the sulfate resistance Test and the chloride resistance test. The cost analysis was also done and results are presented. The test results are promising when vermiculite was used to replace natural sand at 10%.
Key Words: concrete, natural sand, vermiculite, durability, normal aggregate and recycled aggregate, sulfate and chloride.

1. Introduction

The concrete, a versatile material consists of cement, natural sand, normal coarse aggregate, and water. Presently, natural sand is becoming costlier and also scarce. So to continue constructional activities, there is a need for an alternative material for Natural sand. So, M-sand, granite fines are being used to partially replace natural sand in constructions. Vermiculite is evaluated for replacing natural sand because of its superior properties of thermal insulation and sound insulation. The vermiculite acts as filler material and also make concrete lighter. Vermiculite when exfoliated can resist higher temperatures. When used in concrete, this exfoliated vermiculite makes concrete resist higher temperatures. In the present study, an attempt is made to assess the impact of sulfate and chloride on Vermiculite blended concrete.

2. Related Work

Sulfate resistance of concrete is studied over the years, but not properly understood. Out of two sources external and internal, External source is a natural occurring sulfates coming from fertilizers whereas internal source is a one resulting when introduced in the cement. Noor N.M.et.al [1] studied the effect of crumb rubber on concrete strength and chloride ion penetration resistance and proposed that resistance to chlorine is achieved by increasing the content of rubber in concrete at the water cement ratio of 0.35 compared to that of 0.5. Chiara F. Ferrari's et.al [2] during their study of concrete subjected to sulfate

attack insisted that to quickly assess the concrete life, there is a need for simulation models. Sumaiya Binte Huda [3] when studying strength and durability of recycled coarse aggregates emphasized that strength improved after 7 weeks when concrete is subjected to sulfate attack the reason being that continuous hydration happens and voids get it covered by hydrated products. Yingwu Zhou et.al [4] when studying Strength deterioration of concrete in sulfate environment: An experimental study and theoretical modeling, revealed that when the concrete is subjected to dry-wet cycling action of sulfate corrosion that the strength of concrete showed a maximum at 60^{th} day of soaking in sulfate solution.
Jackson Muthengia Wachira et.al [5] while studying Effect of Sulphate and Chloride Ingress on Selected Cements Mortar Prisms Immersed in Seawater and Leather Industry Effluent, revealed that concrete when exposed to sulphate and chloride, there was reduction in compressive strength when compared with conventional sample but compressive strength improved with age for all water cement ratios. Seong-kyum Kim et.al [6] studied about the resistance of reinforced concrete to sulfate attack. This study used flumes containing liquid crystal display waste glass powder. A Sulfate resistance test was carried by immersing specimens in sodium sulfate and magnesium sulfate solutions. They expressed that there is less reduction in weight and volume of the specimens when immersed in sodium sulfate as to that of magnesium sulfate. Peng Liu et.al [7] studied sulfate attack mechanism of cement concrete based on chemical thermodynamics expressed that effect of sulfates on cement concrete was magnificent. Bingol A.F et.al [8] emphasized that sulfate causes certain deteriorations like cracking, expansion and spalling through particular reactions inside concrete. By replacing 10% of cement and 5% of cement of fly ash and silica fume respectively, a better compressive and flexural strength results was achieved when compared to conventional concrete. Aiestein Rozario et.al [9] indicated that use of water soluble polymers in concrete has improved performance of concrete. Otieno, M,et.al [10] revealed that, due to possible incomplete filling of the original device caused the huge ingress of chloride in concrete. Park. J et al. [11] examined that chloride ion diffusion coefficient is less for water cured specimen when compared with air cured specimens. They also felt that with increase in GGBFS replacement ratio, chloride ion diffusion coefficient value decreased. The reason was attributed to higher fineness and hydraulic reactions. Niu, Ditao et.al [12] expressed that in view of attaining sufficient compressive strength and chloride ion resistance of concrete, hybrid fibers in the concrete should not exceed 0.15% by volume.

From the literature Review following objectives are drafted

1. To carry out preliminary tests on cement, sand, vermiculite, Normal coarse aggregate and recycled aggregate.
2. To carry out Slump Cone Test and Compaction Factor Test on Fresh concrete.
3. To carry out weight absorption Test and Split Tensile test on Vermiculite blended concrete with normal aggregate and recycled aggregate separately and compare it with conventional concrete when subjected to sulfate attack.
4. To carry out Carbonation chloride test on Vermiculite blended concrete with normal aggregate and recycled aggregate separately and compare it with conventional concrete when subjected to chloride attack.
5. To carry out cost analysis on various mixes and arrive at optimal mix that can be adopted.

3. Proposed Work

In this study, Vermiculite is used as a filler material. Vermiculite is a hydro-phyllo-silicate mineral which expands on Heating. Vermiculite is light in weight and possesses improved fire resistance. Vermiculite also possesses specific gravity of around 2.1. It exhibits chemical inertness and also resists Cracking and shrinkage on exfoliation. Here coarse aggregate used is plain normal gravel and recycled gravel, natural sand, vermiculite and Cement used is of 53 grade and its properties are shown in Table 1 to table 4.

Table 1 Physical properties of cement

Details	Value	**IS12269-1987 (Reaffirmed 2013)**
Normal consistency	31	-
Initial setting time	65 minutes	Not less than 30 minutes
Final setting time	310 minutes	Not greater than 600 minutes
Soundness	1mm	Does not exceed 10mm
Fineness	6.1%	Does not exceed 10%
Specific gravity	3.145	-

The physical properties of cement like Initial setting time, final setting time, soundness, fineness are confirming to IS 12269. Physical properties like normal consistency and specific gravity are also as per accepted norms.

Table 2 Sand Properties

S.no	**Details**	**Unit**	**Results**
1.	Specific gravity	-	2.61
2.	Bulking of sand	%	3.8
3.	Particle size variation	mm	0.16 to 4.55
4	Water absorption for sand	%	0.9
5	Bulk Density of Sand	kg/m^3	1450
6	Fineness modulus	%	3.1

The properties of sand like specific gravity of sand, Bulking of sand, particle size variation, water absorption, Bulk density of sand and Fineness modulus are as per accepted norms.

Table 3 Characteristics of Vermiculite

S.No	**Properties**	**Values**
1	Color	yellow,
2	Specific Gravity	2.1
3	Fineness modulus	3.2

The properties of Vermiculite, like specific gravity is 2.1 which is less than 2.61 of Natural sand, which, when replacing Natural sand makes concrete lighter in weight. The color of vermiculite considered for this study is yellow. The fineness modulus for vermiculite it was 3.2.

Table 4 Properties of Normal Gravel and Recycled Gravel

S.No	Properties	Values of Normal Gravel	Values of Recycled Gravel
1	Water Absorption	1 %	5.1
2	Specific Gravity	2.72	2.6
3	Crushing Strength	1620 kg/m2	1650 kg/m2
4	Color	Green	Brownish Green
5	Fineness Modulus	2.83	2.96

When comparing the Properties of Normal gravel and Recycled gravel, Specific gravity and crushing strength for recycled gravel is better than normal gravel. There is not much change in Fineness modulus and color for both Normal gravel and recycled gravel. However, water absorption of recycled gravel is more than normal gravel. The reason may be attributed to presence of dried cement paste attached to recycled gravel already. But when used in concrete, recycled gravel provides better interlocking and exhibits lesser water absorption after hardening of concrete.

The slump cone test apparatus was made according to IS: 7320-1974 and used for calculating normal consistency of concrete. Fresh concrete was filled in the slump cone by ramming every layer 25 times. As soon as the slump cone is lifted vertically, the settlement of concrete happens and slump of the concrete is measured by the scale. The compaction factor test setup consists of upper hopper, bottom hopper and the cylinder. First concrete is filled in upper hopper, and then later the trap door is opened. The concrete falls into the bottom hopper. Once the trap door of bottom hopper is opened, concrete deposits into the cylinder. Level the top of cylinder with a trowel and clean outside of cylinder. Weigh the cylinder (w1). Pour the concrete outside and fill it back in to cylinder in different layers. Compact each layer and trim the cylinder top using trowel. Weigh the cylinder (w2). The weight of empty cylinder is taken as w. Compaction Factor is the ratio between (w1-w2) to (w2-w).

For carrying out sulfate resistance test the procedure to be adopted is to choose Sodium sulfate or magnesium solutions using around 2.500 mg to 4.000 mg SO_4^{2}/l at room temperature. In present study Sodium sulfate solution is used. The impact of the sulfate solution is studied by measuring the tensile strength. Split Tensile Test procedure as per IS specifications IS 5816:1999 Split tensile test is to be conducted. The cylinder size is 150 mm diameter and 300 mm length. Cylinders are loaded horizontally in compression testing machine. Application of load is done till cylinder fails. The maximum load on the cylinder was to be observed. Split Tensile strength is given by the ratio of 2N and (π/d) where the d=diameter of cylinder in mm, l= length of cylinder in mm and the N= maximum load applied to the cylinder. The concrete cubes and cylinders are cast using concrete mix design, whose details are provided in table 5 to table 8.

Table 5 Concrete Mix design (As per IS: 456-2000 and IS: 10262-2009)

S.No	Criteria	Description
1	Grade of Concrete	M30
2	Cement	OPC 53
3	Maximum size of aggregate	20 mm
4	Exposure	Moderate

The grade of cement chosen for the study is an OPC 53. The maximum size of aggregate is 20 mm. The exposure conditions of concrete are moderate in preparation of M30 grade of concrete. The mix design for concrete is done as per IS 456 and IS 10262. The Target means strength required is 38.25 N/mm^2.

Table 6 Test data for Materials

S.No	**Test Data for materials**	
1	cement used	Zuari 53-Grade
2	specific Gravity of water	1
3	Chemical Admixture	plasticizer
4	Free(surface) Moisture of coarse aggregate	Nil
5	Free(surface) Moisture of fine aggregate	Nil

The brand of cement used is Zuari cement. The specific gravity of water chosen for the study is 1 and plasticizer is used as a chemical admixture to improve workability. The coarse and fine aggregate is free from moisture.

Table 7 Mix ratio of M30 Grade Concrete

Type of Coarse aggregate	**Water**	**Cement**	**Fine aggregate**	**Coarse Aggregate**
Normal Gravel (CC, M2, M4, M6)	197.16 (W/C Ratio 0.45)	438.13	619.44	1143.59
		1	1.41	2.61
Recycled gravel (M1, M3, M5, M7)	197.16 (W/C Ratio 0.45)	438.13	628.5	1151.37
		1	1.44	2.63

Here in this study, two sets of samples are prepared. The samples CC, M2, M4 and M6 are prepared using Normal gravel with a mix ratio of 1: 1.41:2.61. The samples M1, M3, M5 and M7 are prepared using Normal gravel with a mix ratio of 1: 1.44:2.63. The water cement ratio for both the set of samples is 0.45

Table 8 Specimen specifications

S.No	Sample No	Specifications
1	CC	Conventional concrete with 0% vermiculite and Normal gravel as coarse aggregate
2	M1	Concrete With 0% vermiculite and recycled gravel as coarse aggregate
3	M2	Concrete With 05% vermiculite and Normal Gravel as coarse aggregate
4	M3	Concrete With 05% vermiculite and recycled Gravel as coarse aggregate
5	M4	Concrete With 10% vermiculite and Normal Gravel as coarse aggregate
6	M5	Concrete With 10% vermiculite and recycled Gravel as coarse aggregate
7	M6	Concrete With 15% vermiculite and Normal Gravel as coarse aggregate
8	M7	Concrete With 15% vermiculite and recycled Gravel as coarse aggregate

Here Conventional concrete (CC) is prepared with normal gravel and without vermiculite. The M1 sample was prepared with recycled gravel and without vermiculite. Here for both CC and M1, natural sand was not replaced. For samples M2 and M3, natural sand was replaced by vermiculite by 5%. For samples M4 and M5, natural sand was replaced by vermiculite by 10%. For samples M6 and M7, natural sand was replaced by vermiculite by 15%.

4. Results and Analysis

The results on Fresh concrete and hardened concrete are presented here. Tests included on fresh concrete include workability tests in the form of slump test and compaction factor test. The tests on hardened concrete include split tensile strength test, and durability tests like water absorption test, Sulfate resistance test and carbonation Chloride test. The results are depicted in Table 9-13. The same is represented in Figure 1-4. The cost analysis is done and is shown in Table 14.

4.1 Tests on Fresh Concrete

Table 9 Results on fresh concrete

S.No	Test	Result (cm)	
		Normal Gravel	Recycled gravel
1	Slump Test	12	10
2	Compaction Factor Test	0.89	0.7

The slump test values showed a lesser slump for Recycled gravel when compared to normal gravel. Similar values were also noticed in the compaction factor test.

4.2 Split Tensile strength Test:

Table 10 Spilt Tensile Strength of Vermiculite concrete (0.45) for M30 Grade of Concrete

S.No	Replacement (Sample Number)	Spilt Tensile Strength (N/mm2) Before sulfate resistance test			Spilt Tensile Strength (N/mm2) After sufhate resistance test		
		7 Days (N/mm2)	14 Days (N/mm2)	28 Days (N/mm2)	7 Days (N/mm2)	14 Days (N/mm2)	28 Days (N/mm2)
1	CC	2.43	2.95	3.08	2.05	2.63	2.51
2	M1	1.85	2.12	2.52	1.41	1.83	2.17
3	M2	2.32	2.86	2.90	1.98	2.35	2.28
4	M3	2.46	2.91	3.21	2.08	2.45	2.93
5	M4	2.53	3.05	3.85	2.31	2.82	3.69
6	M5	2.71	3.21	3.97	2.45	2.91	3.84
7	M6	2.39	2.87	3.61	1.89	2.39	3.24
8	M7	2.45	2.98	3.72	2.05	2.56	3.47

Split Tensile strength of M5 Mix has the highest value after exposed to sulfate environment when compared with other mixes. The reason may be attributed to the usage of recycled gravel as coarse aggregate, which is effective in resisting sulfate ingress by possessing good interlocking between fine and coarse aggregate. The exfoliated vermiculite acted as filler material filling the voids thus making concrete specimen free from air voids. So 10% of vermiculite replacing natural sand are effective when compared with other mixes.

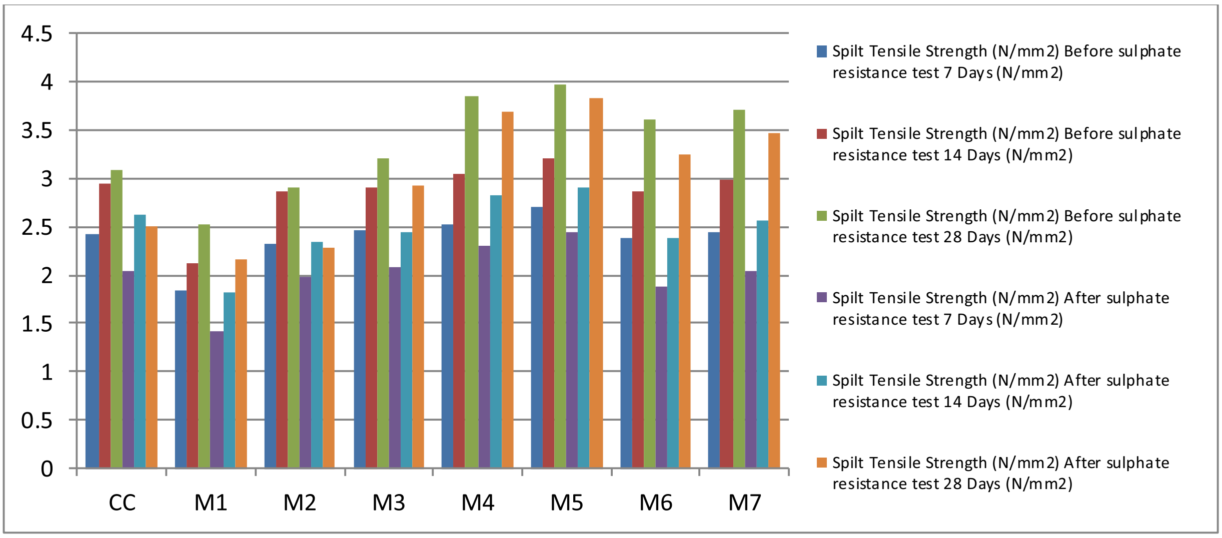

Fig 1: Split Strength Test (Before and after Sulfate Attack) for M30 Grade concrete

The figure 1 clearly depicts that sample M5 could effectively resist ingress of sulfate into concrete when compared with other mixes.

Table 11 Spilt Tensile Strength of Vermiculite concrete (0.45) for M30 Grade with Normal Gravel

S.No	Replacement (Sample Number)	Spilt Tensile Strength (N/mm2) Before sulfate resistance test			Spilt Tensile Strength (N/mm2) After sulfate resistance test		
		7 Days (N/mm2)	14 Days (N/mm2)	28 Days (N/mm2)	7 Days (N/mm2)	14 Days (N/mm2)	28 Days (N/mm2)
1	CC	2.43	2.95	3.08	2.05	2.63	2.51
3	M2	2.32	2.86	2.90	1.98	2.35	2.28
5	M4	2.53	3.05	3.85	2.31	2.82	3.69
7	M6	2.39	2.87	3.61	1.89	2.39	3.24

When plain normal gravel is used in concrete, after exposing to sulfate solution, M4 mix is showing maximum split tensile strength when compared with other mixes after 28 days. All the specimens exhibited a decrease in split tensile strength after soaking in sulfate solution. However, when vermiculite at 10% (M4) replaced Natural sand, better split strength values are obtained. The reason may be attributed to vermiculite which acted as filler material in removing air voids and improving split tensile strength.

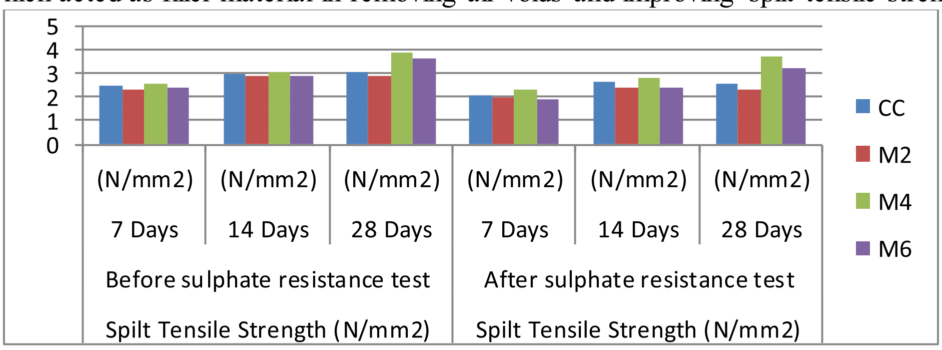

Fig 2: Split Strength Test (Before and after Sulfate Attack) for M30 Grade with Normal Gravel

The figure 2 clearly depicts that sample M4 could effectively resist ingress of sulfate into concrete when compared with other mixes using normal gravel as a coarse aggregate.

Table 12 Spilt Tensile Strength of Vermiculite concrete (0.45) for M30 Grade with recycled gravel

S.No	Replacement (Sample Number)	Spilt Tensile Strength (N/mm2) Before sulfate resistance test			Spilt Tensile Strength (N/mm2) After sulfate resistance test		
		7 Days (N/mm2)	14 Days (N/mm2)	28 Days (N/mm2)	7 Days (N/mm2)	14 Days (N/mm2)	28 Days (N/mm2)
1	CC	2.43	2.95	3.08	2.05	2.63	2.51
2	M1	1.85	2.12	2.52	1.41	1.83	2.17
4	M3	2.46	2.91	3.21	2.08	2.45	2.93
6	M5	2.71	3.21	3.97	2.45	2.91	3.84
8	M7	2.45	2.98	3.72	2.05	2.56	3.47

When recycled gravel is used in concrete, after exposing to sulfate solution, M5 mix is showing maximum split tensile strength when compared with other mixes after 28 days. All the specimens exhibited a decrease in split tensile strength after soaking in sulfate solution. However, when vermiculite at 10% (M5 Mix) replaced Natural sand, better split strength values is obtained. The reason may be attributed to vermiculite which acted as filler material in removing air voids. This in turn improved the split strength values better than control mix. The early strength increase could be attributed to continuous hydration and filling up of pores by compounds formed as a result of the reactions between sulfate and cement hydration products.

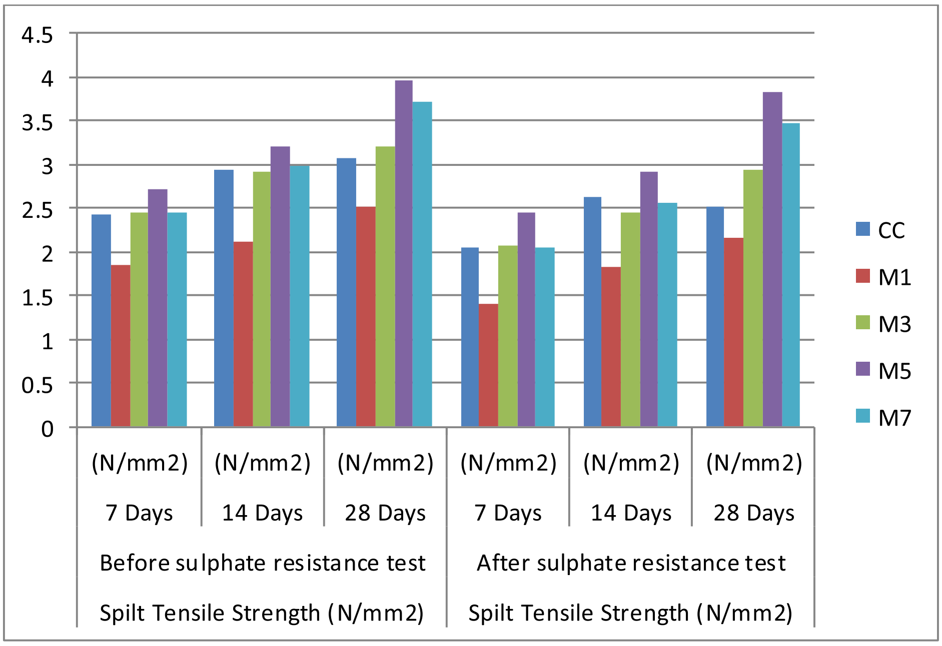

Fig 3: Split Strength Test (Before and after Sulfate Attack) for M30 Grade with recycled aggregate

The figure 2 clearly depicts that sample M5 could effectively resist ingress of sulfate into concrete when compared with other mixes using recycled gravel as a coarse aggregate.

Table 13 Chlorination Depth for different mixes of concrete specimens

S.NO	DESIGN MIX	CHLORINATION DEPTH (mm)
1	CC	**7.10**
2	M1	**7.02**
3	M2	**9.4**
4	M3	**9.15**
5	M4	**8.25**
6	M5	**7.15**
7	M6	**8.35**
8	M7	**7.95**

For M5 Mix Chlorination depth values are almost same as that of conventional sample. The reason may be attributed that usage of recycled aggregate has created good interlocking between fine and coarse aggregate. This in turn decreased the voids. Those available voids are also filled with exfoliated vermiculite which was used as filler material. As voids are filled effectively, the concrete specimen could resist penetration of chlorine when compared with other mixes, which is clearly shown in Table 13 above and fig 4 below.

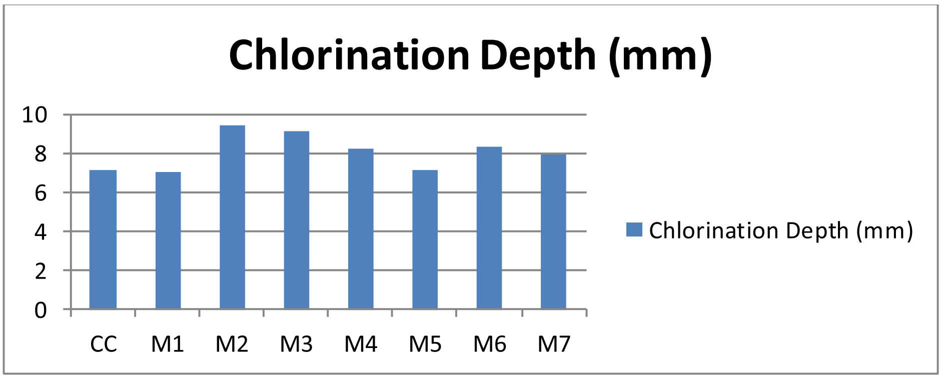

Fig 4: Chlorination Depth (mm)

Figure 4 clearly shows that chlorination depth is more for mix M2 and least for M1. However mix M5 values are almost near to Mix M1 and can be said to effectively resist the chlorine entry into concrete.

4.4 Cost Analysis

Table 14 Cost Analysis of concrete per cubic meter of concrete

Mix	Sand Content	Natural Sand cost	Vermiculite Cost	Recycled Gravel Cost	Normal Gravel Cost	Cement Cost	Total Final Cost (RS)
CC	100%	89	0	0	813	3111	4013
M1	100%	90	0	600	0	3111	3801
M2	95%	85	806	0	813	3111	4815
M3	95%	86	832	600	0	3111	4629
M4	90%	80	1612	0	813	3111	5616
M5	90%	81	1664	600	0	3111	5456
M6	85%	76	2418	0	813	3111	6418
M7	85%	77	2496	600	0	3111	6284

Here
Cost of Sand is Rs.0.143 /Kg
Cost of Crushed Recycled Gravel is Rs.0.52/Kg
Cost of Vermiculite is Rs.26/Kg
Cost of Crushed Normal Gravel is Rs.0.7107/Kg

Here when the cost of M1 mix is compared with that of conventional concrete, it is 6% less, because of lesser cost or recycled gravel when compared with Normal Gravel. When M4 and M5 are compared with conventional concrete the cost is around 40% and 38% more, but superior split tensile strength when compared to conventional concrete and also because of its superior properties like Thermal insulation and better acoustic properties. M4 or M5 mix may be adopted in keeping durability point of View.

5. Conclusion

In this study, because of scarcity of sand, vermiculite in exfoliated form is used to partially replace natural sand at 5%, 10% and 15%. The water cement ratio of 0.45 was adopted. The coarse aggregate used in this study is plain normal aggregate and recycled aggregate. The test conducted on concrete specimens cast includes, Split tensile strength test, Sulfate resistance test, carbonation chloride test and cost analysis.
On comparing the test results, the following conclusions are arrived at:

1. The slump test and compaction factor test indicate that the workability of concrete with recycled gravel is slightly weaker when compared with concrete made with plain normal gravel. However, the difference is very less, so if durability properties are satisfactory, then recycled gravel may be adopted in the place of plain normal gravel.
2. The Split tensile strength values for concrete specimens with recycled gravel are slightly better when compared with concrete specimens with plain normal gravel when tested after 28 days. It is clear from the results of the study that M5 mix was slightly better when compared with M4 mix. Both M4 and M5 mixes are made with vermiculite replacing natural sand at 10%. The test results of the M4 and M5 mixes are better than all other mixes.
3. When the concrete was exposed to sulfate attack and tested for Split tensile strength, the results show that concrete specimens with recycled gravel are slightly better when compared with concrete specimens with plain normal gravel when tested after 28 days. It is clear from the results of the study that M5 mix was slightly better when compared with M4 mix. Both M4 and M5 mixes are made with vermiculite replacing natural sand at 10%. The test results of the M4 and M5 mixes are better than all other mixes because of superior interlocking between aggregates and reduction of air voids, because of usage of exfoliated vermiculite.
4. When the carbonation chlorination test was conducted and depth of chlorine penetration was measured, the M5 mix gave lesser penetration depth when compared with all other mixes. The reason is that when recycled gravel was used in the place of normal plain gravel, because of superior interlocking between aggregates and reduction of air voids, as exfoliated vermiculite fills the air voids, thus not allowing penetration of chlorine in the concrete.
5. Even though the cost of concrete is increasing with the increase in vermiculite content, the special properties like Thermal insulation and acoustic properties. M4 or M5 mix may be adopted in keeping durability point of View.

Considering above results we can conclude that recycled gravel as a coarse aggregate can be used to replace plain normal gravel, when vermiculite is used to partially replace natural sand at 10%.

References

[1] Noor, N. M., Hamada, H., Sagawa, Y., & Yamamoto, D. (2015). Effect of crumb rubber on concrete strength and chloride ion penetration resistance *Jurnal Teknologi*, *77*(32), 171-178. https://doi.org/10.11113/jt.v77.7004

[2] Chiara F. Ferraris, Paul E Stutzman and Kenneth A.Snyder: Sulfate resistance of Concrete: A New Approach, *PCA*, (2006)

[3] Sumaiya Binte Huda: Mechanical and durability properties of Recycled and repeated Recycled coarse aggregate concrete, *The University of British Columbia,* pp 1-122, (2014)

[4] Yingwu Zhou, Hao Tian, **Lili Sui**, Feng Xing, Ningxu Han, “Strength Deterioration of Concrete in Sulfate Environment: An Experimental Study and Theoretical Modeling”,*Advances in Materials Science and Engineering*, Vol. 2015, Article ID 951209, 13 pages, 2015, https://doi.org/10.1155/2015/951209.

[5] Jackson Muthengia Wachira, reginah Wangui Ngari, Joseph Karanja Thiong’o, Joseph Mwiti Marangu, “Effect of Sulfate and Chloride Ingress on Selected Cements Mortar Prisms Immersed in Seawater and Leather Industry Effluent”, *Advances in Civil Engineering*, vol 2019, Article ID 8191689, 16 pages, 2019. https://doi.org/10.1155/2019/819168

[6] Kim, S.-K.; Hong, W.-K. High Sulfate Attack Resistance of Reinforced Concrete Flumes Containing Liquid Crystal Display (LCD) Waste Glass Powder. *Materials* **2019**, *12*, 2031.

[7] Peng Liu, Ying Chen, Zhiwu Yu, Lingkun Chen, Yongfeng Zheng, "Research on Sulfate Attack Mechanism of Cement Concrete Based on Chemical Thermodynamics", *Advances in Materials Science and Engineering*, vol. 2020, Article ID 6916039, 16 pages, 2020.https:// doi.org/10.1155/2020/6916039.

[8] Bingöl, A.F., Balaneji, H.H. determination of Sulfate Resistance of Concretes Containing Silica Fume and Fly Ash *Iran J Sci Technol Trans Civ Eng* **43,** 219–230 (2019).https://doi.org/ 10.1007/s40996-018-0160-x

[9] A. Aielstein Rozario, Dr.C.Freeda Christy, M.Hannah Angelin, 2013, Experimental Studies on Effects of Sulphate Resistance on Self-Curing Concrete, *International Journal of engineering & Technology(IJERT)* Volume 02, Issue 04 (April 2013)

[10] Otieno, M, & Alexander, M. (2015) chloride conductivity testing of concrete-past and recent developments. *Journal of the South African Institution of Civil Engineering*, *57*(4), 55-64. https://dx.doi.org/10.17159/2309-8775/2015/v57n4a7

[11] Park J, Park C, Joh S, Lee H. Effect of Curing Condition on Resistance to Chloride Ingress in Concrete Using Ground Granulated Blast Furnace Slag. *Materials (Basel)*. 2019;12(19):3233. Published 2019 Oct 2. doi:10.3390/ma12193233

[12] Niu, Ditao, Huang, Daguan, Fu, Qiang Experimental investigation on compressive strength and chloride permeability of fiber-reinforced concrete with basalt-polypropolene fibers *Advances in Structural Engineering.* Jul2019, Vol. 22 Issue 10, p2278-2288. 11p