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Replacement of Cement with Wollastonite and Ground Granulated Blast Furnace Slag in Concrete. - A Review

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ABSTRACT: In this era of global warming on vast scale, every possible solution to cut down emission of CO2 is being developed and one of the major emissions takes place from the process of making cement. The main ingredients used for the production of concrete is Ordinary Portland cement. Unfortunately, a large amount of carbon-dioxide gas produce into the atmosphere during the production of cement, which has a major contributor for greenhouse effect and global warming. Cement with GGBS replacement has emerged as a major alternative to conventional concrete and has rapidly drawn the concrete industry attention due to its cement savings, energy savings and cost savings, environmental and socio-economic benefits. the effect of wollastonite on concrete has not been investigated in detail. Wollastonite is a calcium meta-silicate (CaSiO3) mineral with particles similar to cement. wollastonite and its various effects on concrete as partial replacement of cement or sand. they increase the flexural strength of the concrete. It also reduces drying-shrinkage, abrasion loss, water absorption, and enhances concrete durability due to sulfate attack. The literature shows that GGBS and Wollastonite was found to improve the properties of concrete at later age subject to replacement level

Keywords: Cement,, Compressive-Flexural Strength, Ground granulated blast furnace slag (GGBS), Wollastonite.

I. INTRODUCTION

Concrete is one of the most widely used construction materials, it is usually associated with Portland cement as the main component for making concrete. With the over growing urbanization and industrialization the infrastructural development responsible for huge amount of utilization of concrete as a construction material. It is estimated that the production of cement will increase from about from 1.5 billion tons in 1995 to 2.5 billion tons in 2015.Concrete is used globally to build buildings, bridges, roads, runways, sidewalks, and dams. Cement is necessary for construction activity, so it is tightly linked to the global economy.[1]So far India is second largest manufacturer of cement across the globe. Despite being giant producers, we are facing serious Environmental issues. The cement industry is mass producers of Carbon dioxides. To deal with environmental issues we need to find alternate sources. And from many general studies we can conclude that addition of minerals admixtures to concrete gives more durable concrete which is more resistance to environmental agencies responsible for concrete degradation.[1]

One of the biggest issues of growing concern at the moment faced by concrete industries is the impact of cement production on the environment. Cement, an essential constituent of concrete that typically makes up about 12% of the entire concrete mix, is not an environmentally friendly material. The production of cement not only reduces significant number of natural resources but also liberates a considerable amount of CO2 and other greenhouse gases into the atmosphere as a result of decarbonation of limestone and the combustion of fossil fuels. Till date, a number of studies have been done on the performance of replacement of cement in concrete [1]

II. MATERIAL AND PROPERTIES

Wollastonite

Wollastonite is a calcium inosilicate mineral (CaSiO3) that may include little amounts of iron, magnesium and manganese substituting for calcium. It is usually white. It forms when impure limestone or dolomite is subjected to high temperatures and pressures which sometimes occur in the incidence of silica-bearing fluids as in skarns or in contact with metamorphicrocks. It is named after the English chemist and mineralogist William Hyde Wollaston (1766–1828). Some of the properties that create wollastonite so useful are its high brightness and white coloration, low moisture and oil absorption and low explosive content. Wollastonite is used mainly in ceramics, friction products (brakes and clutches), metal making, paint filler, and plastics. Wollastonite is physically white mineral, inert and its fibers are cheaper than carbon or steel micro-fibers.

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Wollastonite microfibers (WMFs) are very fine. The aspect ratio ranges from 3:1 to 20:1, while the length is 0.4 to 0.6 mm and the diameter is 25 to 150 micrometers. There are two main components that form the mineral wollastonite CaO and Si02. In a pure CaSi03, each part forms almost half of the mineral by weight percentage. [2]

Figure 1. Wollastonite Powder [6]

Colour	White
Specific Gravity	2.90
Bulk Density	2800 Kg/m^3
PH	9.9

Table 1.1 Physical properties of wollastonite[4]

2.1.1 Composition

In a pure CaSiO3, each part forms almost half of the mineral by weight: 48.3% of CaO and 51.7% of SiO2. In some cases, little amounts of iron (Fe), and manganese (Mn), and lesser amounts of magnesium (Mg) substitute for calcium (Ca) in the mineral formula. Wollastonite can form a series of solid solutions in the system CaSiO3-FeSiO3 or hydrothermal synthesis of phase in the system MnSiO3- CaSiO.[16]

2.1.2 Geological Occurrence

Wollastonite usually occurs as a common element of a thermally metamorphosed impure limestone, it also might occur when the silicon is due to metamorphism in contact changed calcareous sediments or to contamination in the invade igneous rock. In mainly of these occurrences it is the effect of the follow reaction between calcite and silica with the loss of carbon dioxide: CaCO3 + SiO2 → CaSiO3 + CO2.7Wollastonite may also be formed in a diffusion reaction in skarn, it is developed when limestone within a sand stone is meta-morphosed by a dike, which results in the formation of wollastonite in the sand stone as a result of outer movement of Ca.[16]

2.1.3 Physical and Chemical Properties

Table 1. Chemical properties of Wollastonite[2]

Sr. No	Tests	Test Results
1	SiO_2	1.70%
2	CaO	53.17%
3	Fe_2O_3	0.015%
4	SO_3	0.133%
5	Al_2O_3	0.060%
6	MgO	2.50%
7	LOI	39.80%

2.2 Ground Granulated Blast Furnace Slag (GGBS)

GGBS (Ground Granulated Blast-furnace Slag) is one of the 'greens' of construction materials. It's simply raw material is a very specific slag that is a byproduct from the blast furnaces manufacturing iron. Manufacture of GGBS utilizes all of the slag and produce no major waste stream. Ground Granulated Blast-furnace Slag is a cementitious material whose major use is in concrete and is a byproduct from the blast-furnaces use to make iron. Blast furnaces control at temperatures of about 1,500°C and are fed with a with awareness-controlled mixture of iron ore, coke and limestone. The iron ore is reduced to iron and the left-over materials form a slag that float on top of the iron.9A by product from the blast-furnaces used to make iron.[17] This slag is at times tapped off as a melt liquid and if it is to be used for the manufacture of GGBS it has to be quickly quench in large volume of water. The quenching optimizes the cementitious properties and produces granule similar to coarse sand. This granulated slag is then dry and ground to a fine powder.[5]

Figure 2 GGBS powder [4]

2.1 Chemical Properties of GGBS

Table 2. Chemical properties of GGBS [4]

Sr.No.	Tests	Test Results
1	Alumina oxide, %	12.30
2	Calcium Oxide, %	31.85
3	Magnesium Oxide (MgO), %	8.33
4	Silicon dioxide SiO2%	31.31
5	Sulfate content as Sulfite (SO3),	0.20
6	Ferric Oxide (Fe2O3)	1.02
7	Loss on ignition (LOI) %	0.66

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2.2.2 Physical Properties of GGBS

Table 2.1. Physical properties of GGBS [4]

Colour	Off-white
Specific Gravity	2.8
Bulk Density	1200Kg/m3
Fineness	395m2/Kg

III. Effect of Ground Granulated Blast Slag in Concrete

3.1 Effects on Fresh Concrete

This section provides a brief understanding of the effect of GGBS on freshly mixed concrete properties and its degree of influence. First it should be noted that effect of GGBS vary considerably depends on the degree of replacement on concrete mixtures.

A. Setting Time

Usually, an increase in time of setting expected when GGBF slag is used as a partial replacement for Portland cement in concrete mixtures. The degree to which the time of setting is affected is dependent on the initial temperature of the concrete, the proportion of the blend used, the water-cementitious materials ratio, and the characteristics of the Portland cement [21]. The setting time of concrete with GGBS is generally greater than that of similar concrete with Portland cement. In general setting time increased with the increase in GGBS content [22].

"Peter W.C. Leung" also stated that, GGBS concrete requires longer setting times than Portland cement concrete, probably due to the smooth and glassy particle forms of GGBS. The setting time also increases with increasing percentage of GGBS replacements. The setting times of GGBS concrete are sensitive to low ambient temperatures [21].

B. Workability

Fulton (1974) investigated workability in detail and suggested that a cementitious matrix containing slag cements exhibited greater workability due to the increased paste content and increased cohesiveness of the paste [23]. Wood (1981) reported that the workability and place ability of concrete containing GGBF slag yielded improved characteristics when compared with concrete not containing GGBF slag. He further stated that this result was due to the surface characteristics of the GGBF slag, which created smooth slip planes in the paste [20]. S. Arivalagan, investigated the workability factors of fresh concrete, by partially replacing cement with 20% , 30% and 40% GGBS at different ages and he found that the degree of workability of concrete was normal, 26 cm, 27 cm and 28 cm respectively and it increased with the addition of GGBS[24].

3.2 Effect on Hardened Concrete

This section provides a brief understanding of the effect of GGBS on hardenedd concrete properties and its degree of influence.

3.2.1. Compressive Strength

"S. Arivalagan" investigated the strength and strength efficiency factors of hardened concrete, by partially replacing cement with 20%, 30% and 40% GGBS at different ages. The specimens when tested at 7 and 28 days, showed increase in compressive strength for 20% replacement of cement. Split tensile strength and flexural strength of concrete also increased at 20% cement replacement [24].

"B.Mangamma et.al." investigate the partial replacement of GGBS in a concrete production. He studied the compressive strength of a concrete by replacing GGBS in 10%, 20%, 30%, 40% and 50% of the binding material for M20 and M30. B.Mangamma, conclude that the partial replacement of GGBS increase the strengths at 10%,20%,30% as well as decrease the strength at 40%,50%[3].

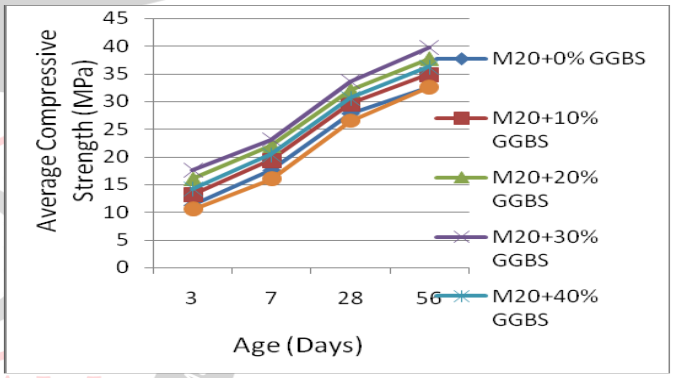

Figure 3 Variation of Compressive strength of M20 grade concrete[3]

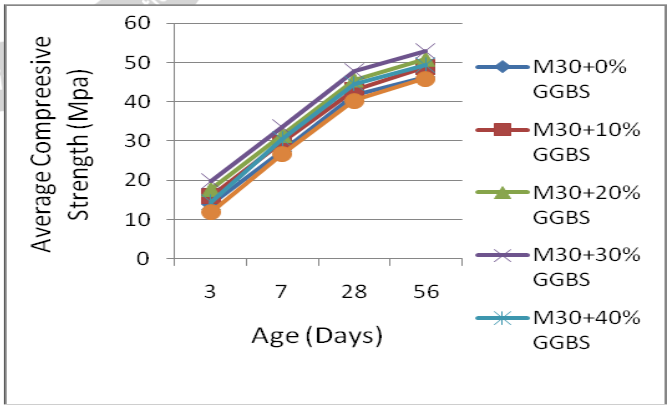

Figure 4 Variation of Compressive strength of M30 grade concrete[3]

"Santosh Kumar Karri et. al." also selected 30%, 40% and 50% as cement replacement levels and cured the specimens of M20 and M40 grade of concrete for 28 and 90 days. He found out that the workability of concrete increases with the increase in GGBS replacement level. He observed that the maximum compressive strength, split tensile strength and flexural strength is achieved at 40% cement replacement for

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both M20 and M40 grade concrete, beyond which the strength decreases slightly.

3.2.2 Tensile Splitting Strength

"Reshma Rughooputhet.al." investigate the partial replacement of GGBS in a concrete production. He studied the tensile strength of a concrete by replacing GGBS in 10%, 20%, 30%, 40%,50 and 60% of the binding material. Reshma Rughooputhet.al, conclude that the GGBS content increases to 30% and 50%, the tensile splitting strength increases by 12% and 17%respectively compared to the 100% OPC mix. When

GGBS is added to the concrete, stronger bonds develop between the GGBS cement paste and the aggregate which leads to a rise in the tensile splitting strength of the test specimens.[3]

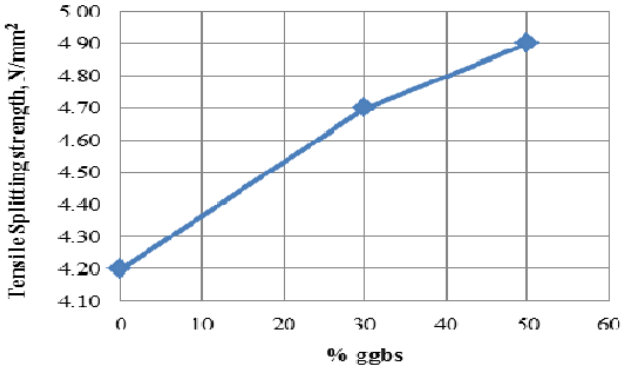

Figure 5 – Variation of tensile splitting with GGBS Content

3.2.3 Drying Shrinkage

The creep of concrete is the deformation of hardened concrete caused by a long-lasting constant load applied on it. Creep, or plastic flow, is the increase in strain with time due to a sustained load. Initial deformation due to the load is an instantaneous strain, while the additional strain due to the same sustained load is the creep stain [26].

Drying shrinkage of concrete is the shrinkage caused by evaporation of internal water in hardened concrete. Creep and drying shrinkage are very important time-dependent properties of high-performance concrete (HPC).

"Reshma Rughooputhet.al." investigate the partial replacement of GGBS in a concrete production. He studied the tensile strength of a concrete by replacing GGBS in 10%, 20%, 30%, 40%,50 and 60% of the binding material. Reshma Rughooputhet.al, conclude that the drying shrinkage tests for all mixes in fig. It is observed that as the OPC is replaced by 30% and 50 % of GGBS, the drying shrinkage increases by 3% and 4% respectively. This confirms that the as the GGBS content increases, the drying shrinkage also increases.[3]

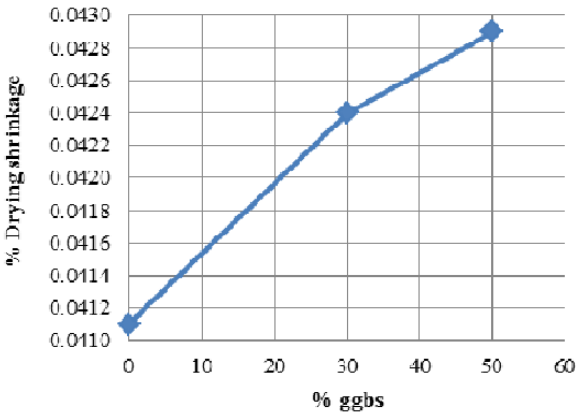

Figure 6 – Variation of drying shrinkage with GGBS Content [3]

4 Effect of Wollastonite

4.1 Effects on Fresh Concrete

This section provides a brief understanding of the effect of wollastonite on freshly mixed concrete properties and its degree of influence. First it should be noted that effect of wollastonite vary considerably depends on the degree of replacement on concrete mixtures.

A. Workability

Performance Comparison of Fly ash And Wollastonite Micro-Fiber in Obtaining Self Compacting Concrete Mixes was studied by **Shashi Kant Sharma et al [7].** In this paper aims to find out the role of fly ash and Wollastonite micro-fiber in obtaining cheap self-compacting concrete for pavements. Workability tests (Abram's flow, V Funnel and J Ring test) have been performed which find out the flow, pass ability and segregation resistance of trial mixes. Load transfer efficiency test has also been performed with successful mixes on a pavement prototype. It was observed, that both fly ash and wollastonite micro-fiber when used alone can't yield self-compaction, but with micro silica content upto 5% they do so, provided their content is lesser than 20% each, respectively. Wollastonite reinforced concrete has two times better load transfer efficiency with respect to normal concrete.

B Compaction Factor

Mohankrishna Reddy investigated Compaction Factor and suggested that the workability of fresh concrete is a composite property which includes the diverse requirements of stability, mobility, compactibility, placeability, and finishability. Compaction factor test is based on the definition, that workability is that property of the concrete which determines the amount of work required to produce full compaction. Compaction factor tests were performed as per BIS: 1199-1959. The test consists essentially of applying a standard amount of work to standard quantity of concrete and measuring the resulting compaction as shown in table . As percentage replacement of wollastonite is increased in concrete its workability decreases.[9]

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Table 3: Compaction Factor Values [9]

Mix	CF	Mix	CF
M0 M1	0.918 0.906	M6 M7 M8	0.917 0.923
M2 M3	0.901 0.896	M9 M10	0.929 0.898
M4 M5	0.886 0.914	M11 M12	0.884 0.868
			0.857

4.2 Effect on Hardened Concrete

This section provides a brief understanding of the effect of wollastonite on hardenedd concrete properties and its degree of influence.

4.2.1 Compressive Strength

"Pawan Kalla" investigated strength properties of concrete by adding wollastonite in it to some desirable percentage with simultaneously replacing the cement percentage by maintaining W/C ratio. Compressive and flexural strength of concrete mixes were evaluated at 0%,10%,15%,20% wollastonite replace by cement. The specimens when tested the maximum compressive strength obtains at uses of 10% wollastonite as a partial replacement of cement.[1]

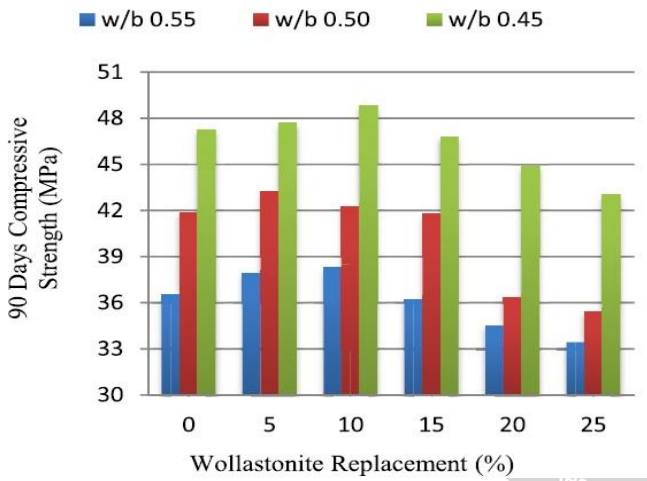

Figure 7- 90 Days compressive strength v/s wollastonite replacement (%).[1]

In this paper investigated the results of a study the Strength of Concrete by Adding Wollastonite in It by M. Borkar S. Zade et al [2]. In this paper particular they are studying the strength properties of concrete by adding wollastonite in it to some desirable percentage with simultaneously replacing the cement percentage by maintaining W/C ratio. This would further help in reducing cement production and thus the greenhouse effect at some extent. [2] In this paper they will study the amount of cement which can be replaced without affecting the strength of concrete Compressive and flexural strength of concrete mixes were evaluated at 0%,10%,15%,20% wollastonite replaces by cement. The maximum compressive strength obtains at uses of 10% wollastonite as a partial replacement of cement. The cost of the structure can be reduced if the wollastonite is used as partial replacement of cement due to its small cost than cement. Hence the use of wollastonite acts as a sustainable material, which can be used in green building theory. M. Borkar S. Zade et al [2].

Shubham Dahiphale et al. [5] presented the study on Properties of Concrete Containing Wollastonite. In this study wollastonite was used to replace cement in concrete mix up to 30 %. There were 9 concrete mixes prepared with different wollastonite percentages which are 0%, 5%, 10%, 12.5%, 15%, 17.5%, 20%, 25%, 30% by weight of cement. It was observed that there was a rise in compressive strength at 10%, 12.5%, 15% wollastonite replacement as compared to control mix. Highest rise was observed at 15% wollastonite replacement. There was slight decrease in compressive strength at 5 % replacement but at 10%, 12.5% & 15% replacement there was rise in compressive strength. Optimum percentage of replacing cement with wollastonite selected is 15%. It is advantageous to use wollastonite in replacement of cement as it reduces pollution. Shubham Dahiphale et al. [5]

4.2.2 Tensile Splitting Strength

"Mohankrishna Reddy" investigated strength properties of concrete, it was observed that in the increase in split tensile strength was observed gradually up to 10% replacement of cement by wollastonite and then decreased. The maximum split tensile strength was obtained with mix (M2) 10% wollastonite replacement which was 15.57% more compared to reference mix. Variation of split tensile strength of M35 grade with different percentage replacement of cement by wollastonite is as shown in figure 8.

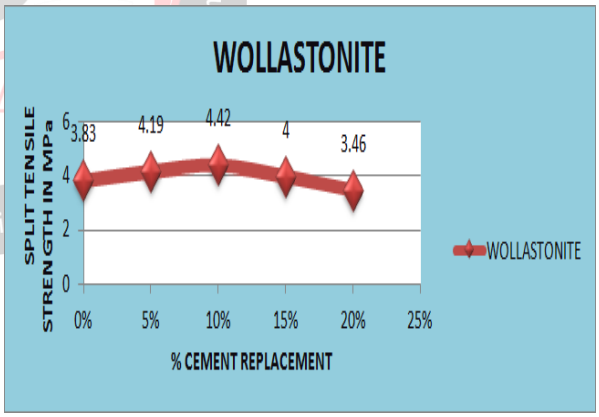

Figure 8: Relation between % Wollastonite Replacement and Split Tensile Strength [9]

Split tensile strength of M35 grade were studied with combination of 10% wollastonite and 5%, 10%, 15% and 20% fly ash replaced with cement. Mix with M35 grade with 10% wollastonite replacement and 15% fly ash obtained maximum strength among all fly ash replacements. It was observed that as fly ash percentage in concrete increased, its split tensile strength increased up to 15% and then decreased. The maximum split tensile strength was obtained at 10% wollastonite and 15% fly ash (M7) obtained a split tensile

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strength 4.62N/mm2 which was 20.8% more than the reference

mix (M0). Variation of split tensile strength of concrete with 10% wollastonite and different percentages of fly ash is as shown in figure 9. Split tensile strength of M35 grade were studied with combination of 10% wollastonite replacement and 5%, 7.5%, 10% and 15% silica fume replaced with cement. Mix with M35 grade with 10% wollastonite and 10% silica fume obtained maximum strength of all silica fume replacements.

It was observed that as silica fume percentage in concrete increased, its split Tensile strength increased up to 10% and further decreased. Mix with 10% wollastonite and 10% silica fume (M11) replacement obtained split tensile strength 4.73N/mm2 which was 23.74% more than the reference mix. Variation of split tensile strength of concrete with 10% wollastonite and different percentages of silica fume is as shown in figure 6. Percentage of split tensile strength of different mixes with reference mix shown is in figure 10.

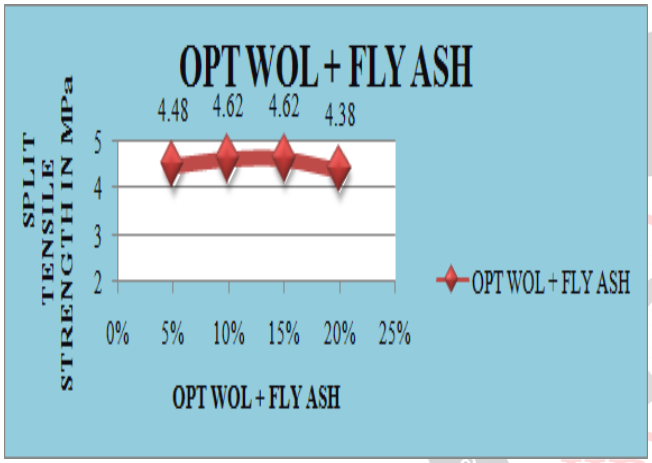

Figure 9: Relation Between Opt Wollastonite (10%) +% Fly Ash Replacement and Split Tensile Strength [9]

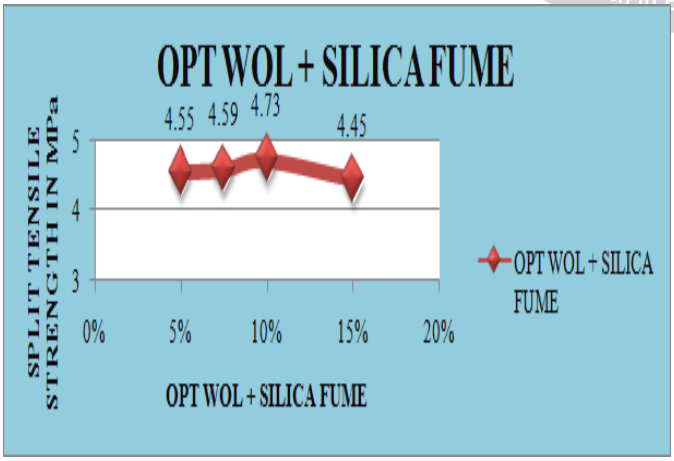

Figure 10: Relation between Opt Wol (10%) +% Silica Fume Replacement and Split Tensile Strength [9]

Influence of wollastonite on mechanical properties of concrete was carried out by **Renu Mathur et al [10]** Studies was made on cement concrete and cement-fly ash concrete mixes incorporating wollastonite as partial substitute of cementitious material and sand respectively. Improvements in compressive (28-35%) and flexural strength (36-42%) at 28 and 56 days respectively were observed by incorporation of wollastonite (10%) in concrete mixes. By incorporation of wollastonite, reduction in water absorption, drying-shrinkage and abrasion loss of concrete, and enhancement in durability against alternate freezing-thawing and sulphate attack were observed. Because of high concrete strength and abrasion resistance, a better utilization of concrete cross section is possible. Alternatively, thickness of pavement slab can be reduced by incorporation [10]

Vikram Singh Meena et al [8] carried out the study related Wollastonite: An Energy Efficient Building Material, this paper present sustainable use of calcium meta silicate mineral "wollastonite" (CaSio3) as a partial replacement of cement. Six concrete mixes were prepared by replacing cement with wollastonite (0-25%). Test result showed that 10% wollastonite can effectively replace cement with improvement in strength and durability parameters. wollastonite can efficiently substitute cement without affecting mechanical parameters of concrete. Replacing 10% cement can even enhance the longevity of concrete structures. Incorporation of wollastonite in cement production will help in sustainable development of country. Test results indicated that the gainful utilization of wollastonite as building material will contribute to sustainable development of country by reducing greenhouse emissions and depletion of natural resources.[8]

4.2.3 Rapid Chloride Permeability Test

"Soham Chudiwal" investigated the RCP test in paper of Experimental Investigation of Fly ash, Marble dust and Wollastonite powder-based Paver block.in this paper Rapid Chloride permeability test is conducted on four combinations of paver block. Test is used for determining the durability of concrete Is code used for this test is IS: 516-1959. [6]

Table 4: RCP test results [6]

Combination	Chloride ion permeability at 7 day	Remark	Chloride ion permeability at 7 day	remark
C1	3150	moderate	2560	Moderate
C19	2052	Moderate	1450	Low
C23	2466	Moderate	2320	Moderate
C24	1746	Low	1420	Low

In this paper auther conclude the result of RCPT test is a measure of performance of concrete under acid attack. Test is conducted only on four combinations, if chloride permeability is less that means it has more resistance

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capacity to acid attack. Marble dust and Wollastonite powder when used together in concrete it has less permeability than normal concrete. [6]

IV. CONCLUSION

Based on the studies of diverse researchers on partial replacement of cement with GGBS and Wollastonite, some relevant conclusions are drawn which are as follows: -

- Workability of concrete increases with the increase in GGBFS replacement level.
- In this study, Partial replacement of GGBS increase the strengths at 10%,20%,30% as well as decrease the strength at 40%,50%. It also reduce the cost of construction.
- In most of the cases, compressive strength decreases with the increase in percentage of GGBS at early age but it increases with increase in percentage of GGBS at later ages.
- Split tensile strength and flexural strength also decreases with the increase in percentage of GGBS at early age but it increases with increase in percentage of GGBS at later ages.
- As percentage of replacement of wollastonite increased in concrete, its workability decreased.
- It was observed that among all percentages of replacement of cement by wollastonite maximum increase in strength occurred at 10% of wollastonite.
- Based on researcher paper, it is observed that there is significance improvement in the strength properties of concrete with wollastonite and silica fume combination when compared to wollastonite and fly ash.
- In this study conclude the Incorporation of wollastonite in the range of 10-15% indicated improvement in concrete's strength and durability.
- Wollastonite powder can be used up to 15% it gives strength to concrete; fire resistance of concrete also increases.
- Heat of hydration is slower in case of GGBS cement, which lowers the risk of shrinkage cracking, and make this cement more favorable in high temperature construction areas.
- In the present paper, showed the cement replacement with different materials with single materials replacement. Further, studies can be carried out in accordance to the replacement of combination of two or more materials with replace cement or aggregates.
- Investigation can be further carried out by partial replacement of wollastonite with GGBS, silica fume, red mud for replacement of cement.

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