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EFFECT OF WOLLASTONITE AND GGBS AS PARTIAL CEMENT REPLACEMENT ON THE PROPERTIES OF CONCRETE

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ABSTRACT

Depletion of natural resources and emission of carbon dioxide is the major factors associated with cement production. This problem can be solved by Partial replacement of concrete ingredients with waste or natural materials like fly ash, GGBS, silica fume, wollastonite, and waste glass powder. Partially replacing cement with wollastonite and ground granulated blast furnace slag(GGBS) helps in reducing environmental pollution. Wollastonite is abundantly available in India's Udaipur belt of Rajasthan state as a low-cost material. This present work has aimed to determine the influence of the wollastonite-GGBS (w-GGBS) combination on the mechanical and durability properties of M50-grade concrete. We study the strength properties of concrete with wollastonite (5%, 10%, 15%, 20%). The optimum percentage of wollastonite in concrete corresponding to maximum strength will be identified. Keeping this optimum percentage of wollastonite replacement as constant, cement is further replaced with mineral admixture such as GGBS(5%, 10%, 15%, 20%). Test results indicated that the replacement of 15% wollastonite with cement shows better results than the conventional mix. The maximum increase in strength was observed in a mix that consists of 15% wollastonite and 15% GGBS.

Keywords: Wollastonite, GGBS, Mechanical properties, Durability properties.

I.INTRODUCTION

Due to the rapid growth of industrialization, a huge quantity of waste is generated which is being disposed of. One of the major challenges with environmental awareness and scarcity of space for landfilling is waste/by-product utilization as an alternative to disposal. GGBS are industrial by-products that can be used as a partial replacement of cement in concrete, otherwise, they would end up in a landfill.

Wollastonite is a naturally occurring calcium meta silicate($CaSiO_3$) mineral with needle-like crystal structures. White silicate mineral of high modulus of elasticity. It is formed due to the interaction of lime-stone with silica in hot magmas. Available in abundance along the Udaipur belt of Rajasthan state of India. As a low-cost material, wollastonite can be ground into a fine powder and is already finding applications in paint, dental care, ceramic tiles, metallurgy, concrete, and other fields. its composition of nearly equal proportions of lime and silica having fine particle sizes were favourable indicators for its admixing in concrete by partial replacement of cement. In addition to its natural availability, wollastonite can be artificially synthesized at relatively low temperatures (900-1200^{o}C) using calcium-containing and SiO_2 minerals, thus wollastonite has a wide range of sources. from an environmental perspective, using natural wollastonite powder as the binder reduced the cement mixing ratio, reducing CO2 emissions and making concrete production suitable. Therefore, the application of wollastonite powder in the field of civil construction has attracted increasing attention from researchers.

Ground granulated blast furnace slag(GGBS) is a by-product of the blast furnace used to make iron. These operate at a temperature of about 1500 degrees centigrade and are fed with a carefully controlled mixture of iron ore that is reduced to iron and the remaining materials from slag that floats on top of the iron. This slag is periodically tapped off a molten liquid and if it is to be used for the manufacture of GGBS it has to be rapidly quenched in larger volumes of water. This quenching optimizes the cementitious properties and produces granules similar to coarse sand. This granulated slag is then dried and ground to a fine powder. It can be referred to as GGBS or slag cement.

Thus, GGBS acts as pozzolans and is therefore combined with Portland cement; resulting in a hardened cement of GGBS combined with Portland cement, which has more of smaller gel pores and fewer larger capillary pores than that of normal Portland cement which consequently results in lower permeability and hence greater durability. This paper presents experimental work carried out to determine the effects of partial replacement of OPC with GGBS and wollastonite.

II.LITERATURE REVIEW

Several authors have reported the use of wollastonite in various civil engineering applications.

Vijay Bhudiya and Abbas Jamani[1]: studied the slump, compression, and tensile strength of concrete by partial replacement of cement with wollastonite and GGBS for M20, M30, and M40 grades of concrete. The compression strength of concrete by partial replacement of cement with 20% of GGBS and 20% wollastonite is observed to be improved (15-20%)compared with the control mix. The durability of the concrete increases with an increase in GGBS content.

Renu Mathur et al [2]: studied the cement concrete and cement fly ash concrete mixes incorporating wollastonite as a partial substitute for cementitious material and sand respectively. Improves in compressive strength (28-35%) and flexural strength (36-42%) at 28 and 56 days respectively were observed by the incorporation of wollastonite (10%) in concrete mixes. By incorporation of wollastonite, reduction in water absorption, drying shrinkage and abrasion loss in concrete, and enhancement in durability against alternate freezing-thawing and sulphate attack were observed.

Aditya Rana [3]: studied eighteen concrete mixes at three w/b ratios (0.45,0.50 and 0.55) that were prepared by substituting Portland cement with wollastonite at varying replacement levels (0 to 25%). Substitution of 10-15% cement by wollastonite resulted in improved strength and durability of concrete. SEM and MIP results indicated the substitution of cement by wollastonite up to 15% reduced porosity and densified the concrete microstructure.

Wahab et al.[4]: investigated the wollastonite as a partial replacement of cement and sand with replacement levels of 10% to 30% with an interval of 10%. The tests such as compression and flexural drying shrinkage were conducted. Due to the incorporation of wollastonite as 30% cement replacement, the compression and flexural strength are enhanced up to 35% and 17% respectively.

A.M Soliman et al.[5]: studying the effect of incorporating wollastonite microfibres in ultrahigh-performance concrete (UHPC). Wollastonite microfibres were added at 0,4,8 and 12% as partial volume replacement for cement. increasing in wollastonite microfibre content resulted in a compressive strength comparable to or higher than that of the control mixture without microfibres. Wollastonite microfibre reduced shrinkage strains and increased cracking resistance compared to that of the control mixture. The addition of wollastonite microfibres with a high aspect ratio improved the hydration process of the UHPC matrix by providing more space for hydration production to form.

Dahiphale et al.[6]: studied the properties by replacing the cement with wollastonite up to 30% with a w/c of 0.44. the compression strength was tested for 3,7 and 28 days. Compression strength increased at 10%, 12.5%, and 15% of wollastonite replacement, due to silica in wollastonite, and then there is a decrease in strength at a higher percentage. It was found that 15%repacement of cement by wollastonite is the optimum percentage from a strength point of view.

Kalla et al.[7]: Examine the durability and mechanical properties of cement-wollastonite-flash-based ternary blended concrete. Concrete using cement partially replaced by a wollastonite-fly ash combination had their compression and flexural strength and durability increased significantly. The researchers concluded that 10-15% replacement of wollastonite resulted in denser, more durable, and highly compressive strength concrete.

Dr N. Vinod babu and G. Hymavathi [8]: when GGBS is a partial replacement for cement it increases the strength of the cubes as well reduces the pollution of the environment. In this study, GGBS was used at 10%, 20%, 30%, 40%, and 50% for M20 and M30 grades. It gives an increase in strength values at 10%, 20%, and 30% compared to control mixes.

Research Significance

With the addition of supplementary cementitious materials in concrete, it is possible to have a favourable influence on many properties either purely physical effects associated with the presence of very fine particles or through physical-chemical effects associated with mineral admixture reactions, which results in modification of the pore structure. The utilization of supplementary cementitious material in concrete improves its strength and durability and makes it cost-effective. Wollastonite is one naturally occurring pozzolanic mineral that can be used in concrete. With ever-increasing quantities of industrial by-products and waste materials, solid waste management has become the principal environmental concern in the world. With the scarcity of landfilling space and due to its ever-increasing cost, utilization/recycling of by-products/ waste has become an attractive alternative to disposal. Several types of by-products and waste materials are generated. Each of these waste products has a specific effect on the properties of cement-based materials. The utilization of such materials in concrete not only makes it economical but also do help in reducing disposal problems. Ground granulated blast furnace slag (GGBS) is an industrial by-product that can be utilized as partial cement replacement in concrete. In this work, the effects of the utilization of wollastonite and mineral admixtures on concrete were investigated. The data obtained in this investigation will be used to establish mix proportions for concrete and construction applications.

III.EXPERIMENTAL PROGRAM

Materials

Ordinary Portland (53 grade) Birla A1 cement was used, and its properties are tested as per IS 12269-1987 and are shown in table 1. The superplasticizer used is FOSROC CONPLAST SP430 which is a sulfonated naphthalene polymer. Its specific gravity is 1.21. wollastonite and GGBS are used as cement replacements in the present study. Wollastonite is obtained from Royalty minerals, Mumbai. GGBS is obtained from Astra Chemicals, Chennai.

Table 1: Properties of cement

Characteristics	Values obtained	Standard values as per our Code 12269-1987
Initial setting time	48 min	Not be less than 30 min
final setting time	315 min	Not be less than 600 min
Fineness (%)	3.8	< 10
Specific gravity	3.10	-
Compressive strength	58 N/mm^2	Not be less than 53 N/mm^2

The physical and chemical properties of wollastonite and GGBS is given by the suppliers shown in table 2. Locally available river sand was used as a fine aggregate and was tested as per Indian standard specifications IS: 383-1970 and their physical properties are given in table 3. The coarse aggregate used in this study was less than 20mm nominal size, tested as per Indian standard specifications IS: 383-1970, and its physical properties are given in table 3.

Table 2: Properties of Wollastonite and GGBS

Physical Properties		
Characteristics	**Wollastonite**	**GGBS**
Colour	White	Off-white
Specific gravity	2.97	2.85
Size(µm)	<1 to 20	<1 to 100

Bulk density(Kg/m^3)	350-1230	1000-1100
Surface area (m^2/kg)	1500	450-550
Chemical Properties		
Chemical composition	**Wollastonite**	**GGBS**
CaO	45-48	40-45
SiO_2	46-52	32-38
Al_2O_3	3-5	13
Fe_2O_3	0.75	0.37
MgO	0.88	8

Table 3: Properties of Aggregate

characteristics	Specific Gravity	Fineness Modulus	Bulk Density (kg/m^3)
Fine aggregate	2.66	3.22	1430
Coarse aggregate	2.8	6.23	1402

Preparation and casting of specimens

The different concrete specimens such as cubes (100mmX100mmX100mm) to determine compressive strength, cylinders (100mm diameter and 200 mm length) to determine split tensile strength and beams (100mmX100mmX500mm) to determine flexural strength were cast. All the specimens were prepared by Indian standard specifications IS:516-1959. All the moulds were cleaned and oiled properly. These were securely tightened to the correct dimensions before casting. Care was taken that there are no gaps left from where there is a possibility of leakage of slurry. A careful procedure was adopted in the batching, mixing and casting operations. Vibrations were stopped as soon as the cement slurry appeared on the top surface of the mould. The specimens were removed from moulds after 24 hours and cured in water till testing as per the requirement of the test.

Experimental Procedure

An experimental investigation has been carried out concerning mix M50 grade concrete. Reference mix (M0) was prepared for M50 grade of concrete as per IS: 10262-2009. Four concrete mixes (M1, M2, M3, M4) were prepared where cement was replaced with 5%, 10%, 15% and 20% wollastonite respectively. It has been observed that concrete with 15% replacement attains maximum strength properties. Hence 15% replacement of cement with wollastonite was kept constant and cement is further replaced with mineral admixtures such as GGBS at 5%, 10%, 15%, and 20% and the specimens were tested. A constant water-cement ratio of 0.38 was adopted for all mixes throughout this study. The mix proportion of reference mix M0 is shown in table 4.

Table 4: Mix Proportions of Reference Mix (Kg/m^3)

Mix	Cement (kg/m^3)	Fine aggregate(kg/m^3)	Coarse aggregate(kg/m^3)	Water(lit)	Superplasticiser by %wt of cement
M0	410	660.8	1356.3	143	1

IV.RESULTS AND DISCUSSIONS

Compressive Strength

The compressive strength of the reference mix (M0) and all mixes cast using wollastonite, GGBS is shown in table 5.

It was observed that the increase in compressive strength was observed up to 15% replacement of cement by wollastonite and then decreased. The maximum compressive strength of 65 N/mm^2 was obtained with a mix (M3) of 15% wollastonite which was 10.16% more compared to the reference mix. Variation of compressive strength of M50 grade with different percentage replacement of cement by wollastonite is shown in figure 1.

Table 6: compressive strength of concrete and % change with reference mix

Mix	compressive strength in MPa	% change
M0	59	-
M1	62	5.08
M2	63.5	7.62
M3	65	10.16
M4	60	1.69
M5	61.5	4.23
M6	63	6.35
M7	66.5	11.86
M8	62	6.77

The compressive strength of M50 grade was studied with a combination of 15% wollastonite and 5%, 10%, 15%, and 20% GGBS replaced with cement. Mix with M50 grade with 15% wollastonite and 15% GGBS obtained maximum strength among all GGBS replacements. As the GGBS percentage in concrete increased, its compressive strength increased up to 15% and then decreased. The maximum compressive strength was obtained at 15% wollastonite and 15% GGBS (M7) obtained a compressive strength of 66.5N/mm^2 which was 11.86% more than the reference mix (M0). Variation of compressive strength of concrete with 15% wollastonite and different percentage of GGBS is shown in figure 2.

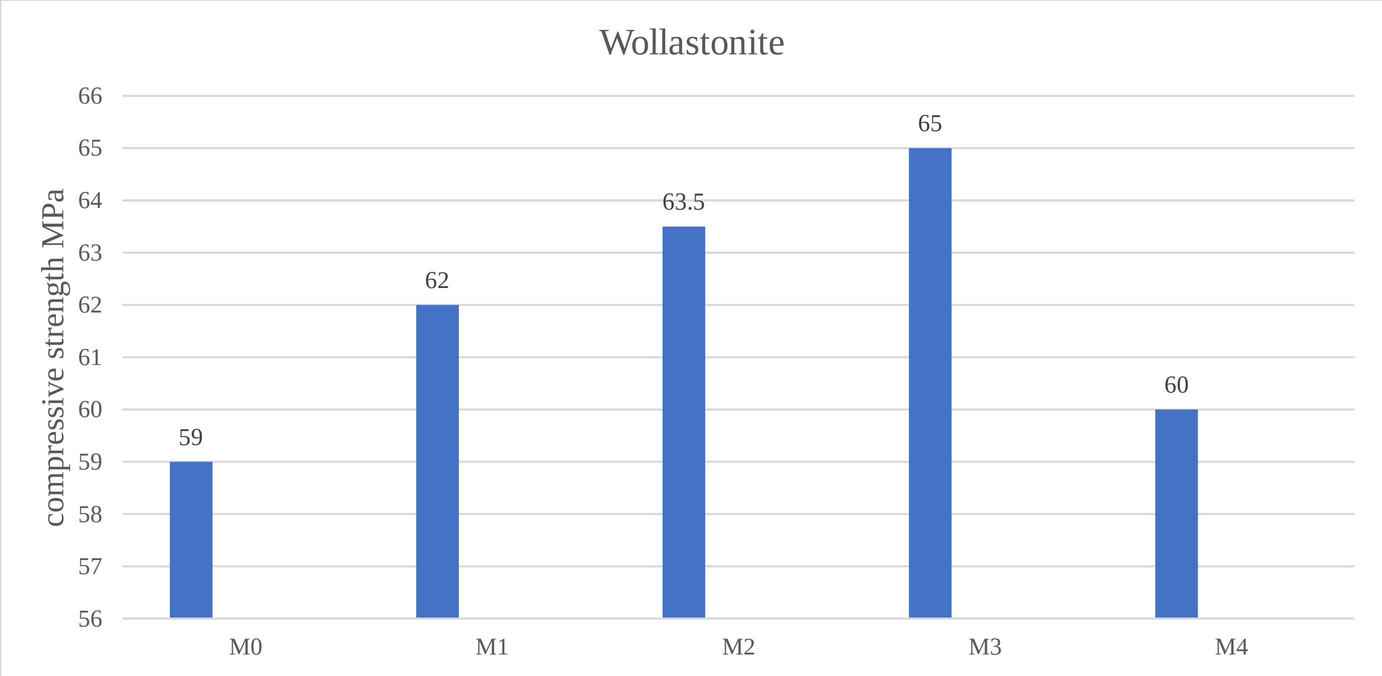

Figure 1: Relation between % wollastonite replacement and compressive strength

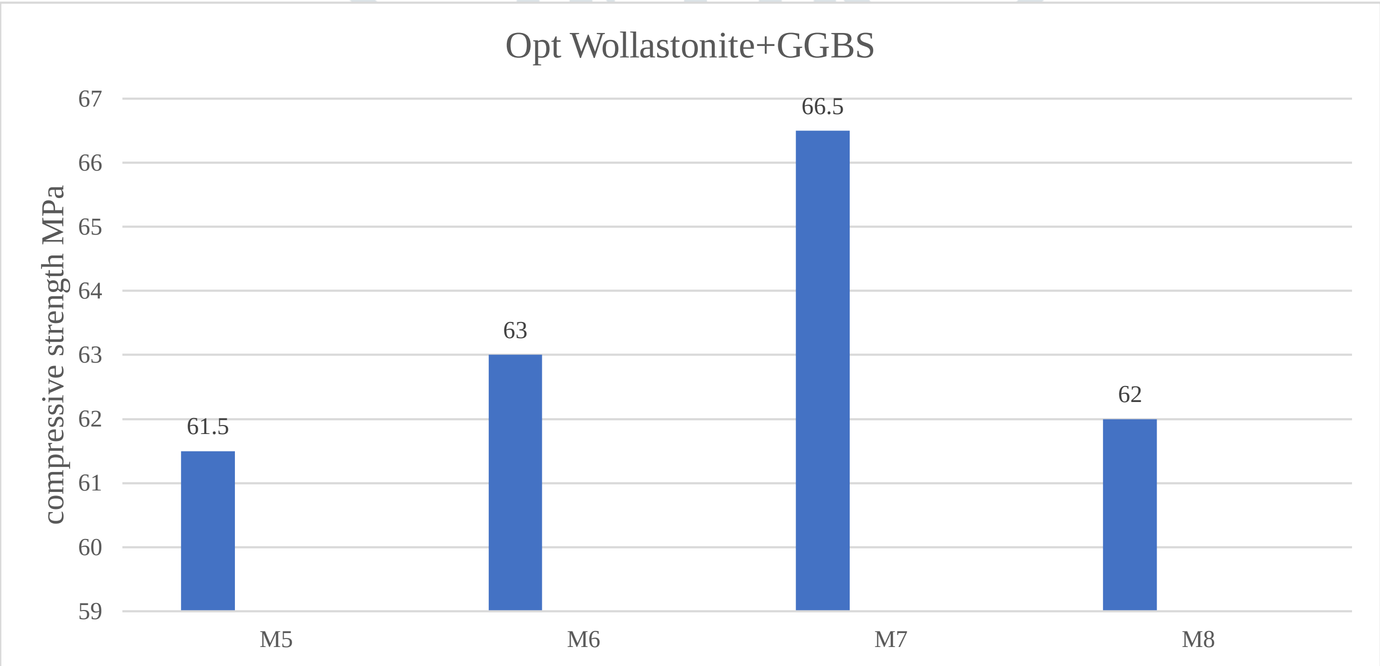

Figure 2: Relation between opt wollastonite(15%)+ % GGBS replacement and compressive strength

Split Tensile Strength

The split tensile strength of the reference mix (M0) and all other mixes cast using Wollastonite, GGBS are shown in table 6.

It was observed that the increase in split tensile strength was observed gradually up to 15% replacement of cement by wollastonite and then decreased. The maximum split tensile was obtained with a mix (M3) of 15% wollastonite which was 16.6% more compared to the reference mix. Variation of split tensile strength of M50 grade with different percentage replacement of cement by wollastonite is shown in figure 3.

Table 6: Split Tensile Strength of concrete and % change concerning the reference mix

Mix	Split Tensile Strength MPa	% Change
M0	4.93	-
M1	5.02	1.82
M2	5.25	6.49
M3	5.75	16.6
M4	4.77	-3.24
M5	4.9	-0.6
M6	5.2	5.47
M7	5.92	20.08
M8	4.8	-2.63

The split tensile strength of M50 grade was studied with a combination of 15% wollastonite and 5%, 10%, 15%, and 20% GGBS replaced with cement. Mix with M50 grade with 15% wollastonite and 15% GGBS obtained maximum strength among all GGBS replacements. As the GGBS percentage in concrete increased, its split tensile strength increased up to 15% and then decreased. The maximum split tensile strength was obtained at 15% wollastonite and 15% GGBS (M7) obtained a split tensile strength of 5.92N/mm² which was 20.08% more than the reference mix (M0). Variation of split tensile strength of concrete with 15% wollastonite and different percentage of GGBS is shown in figure 4.

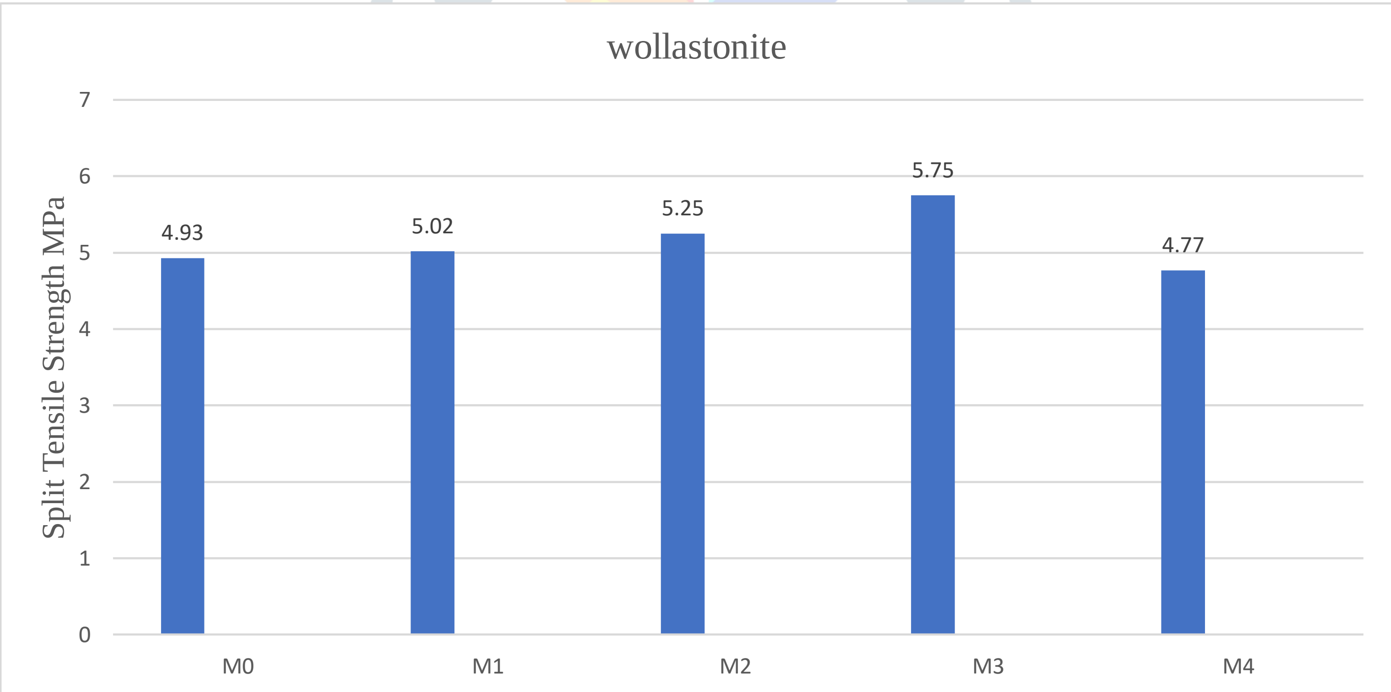

Figure 3: Relation between % wollastonite replacement and split tensile strength

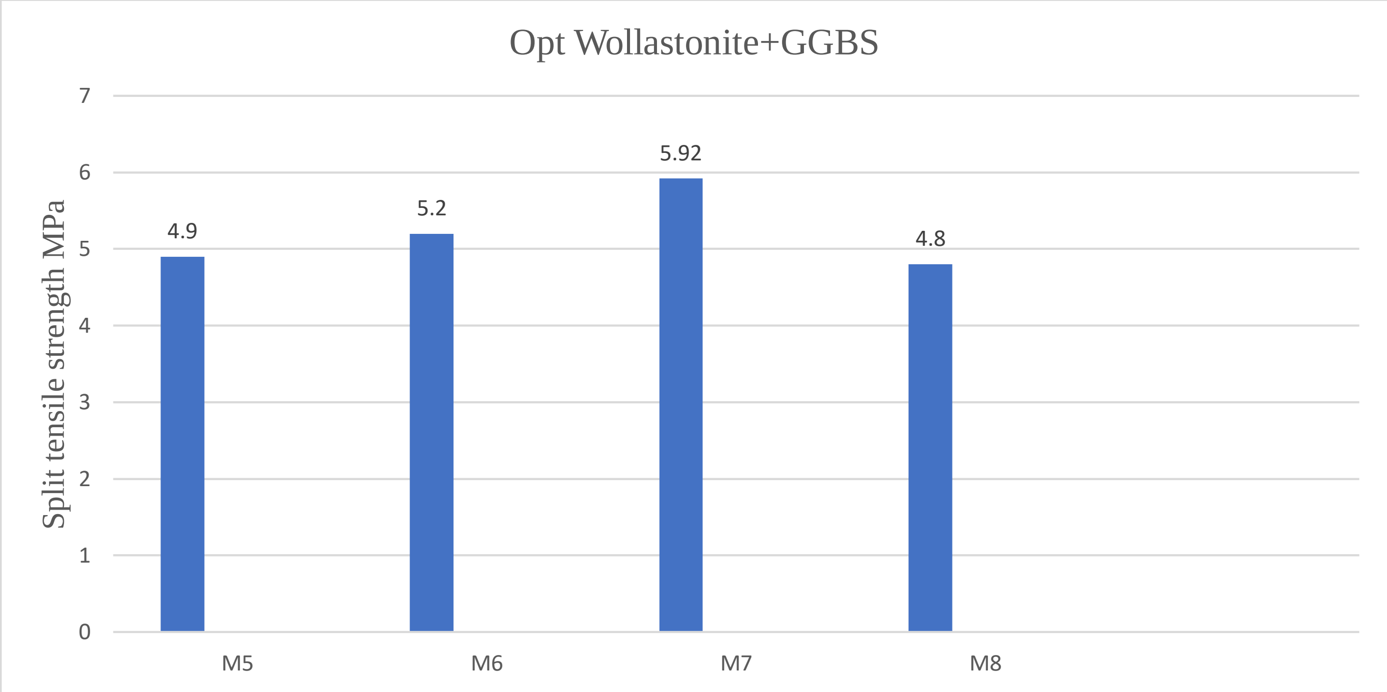

Figure 4: Relation between Opt wollastonite(15%)+% GGBS replacement and split tensile strength

Flexural Strength

The flexural strength of the reference mix (M0) and all other mixes cast using wollastonite, GGBS is shown in table 7. It was observed that the increase in flexural strength was observed up to 15% replacement of cement by wollastonite and then decreased. The maximum flexural strength was obtained with a mix (M3) of 15% wollastonite which was 10.67% more compared to the reference mix. Variation of flexural strength of M50 grade with different percentage replacement of cement by wollastonite is shown in figure 5.

Table 7: Flexural strength of concrete and % change concerning the reference mix

Mix	Flexural strength in MPa	% Change
M0	6	-
M1	6.16	1.66
M2	6.3	5
M3	6.64	10.67
M4	6.1	1.6
M5	6.25	4.16
M6	6.4	6.66
M7	6.69	11.5
M8	6.3	5

The flexural strength of M50 grade was studied with a combination of 15% wollastonite and 5%, 10%, 15%, and 20% GGBS replaced with cement. Mix with M50 grade with 15% wollastonite and 15% GGBS obtained maximum strength among all GGBS replacements. As the GGBS percentage in concrete increased, its flexural strength increased up to 15% and then decreased. The maximum flexural strength was obtained at 15% wollastonite and 15% GGBS (M7) obtained a flexural strength of 6.69N/mm^2 which was 11.5% more than the reference mix (M0). Variation of flexural strength of concrete with 15% wollastonite and different percentage of GGBS is shown in figure 6.

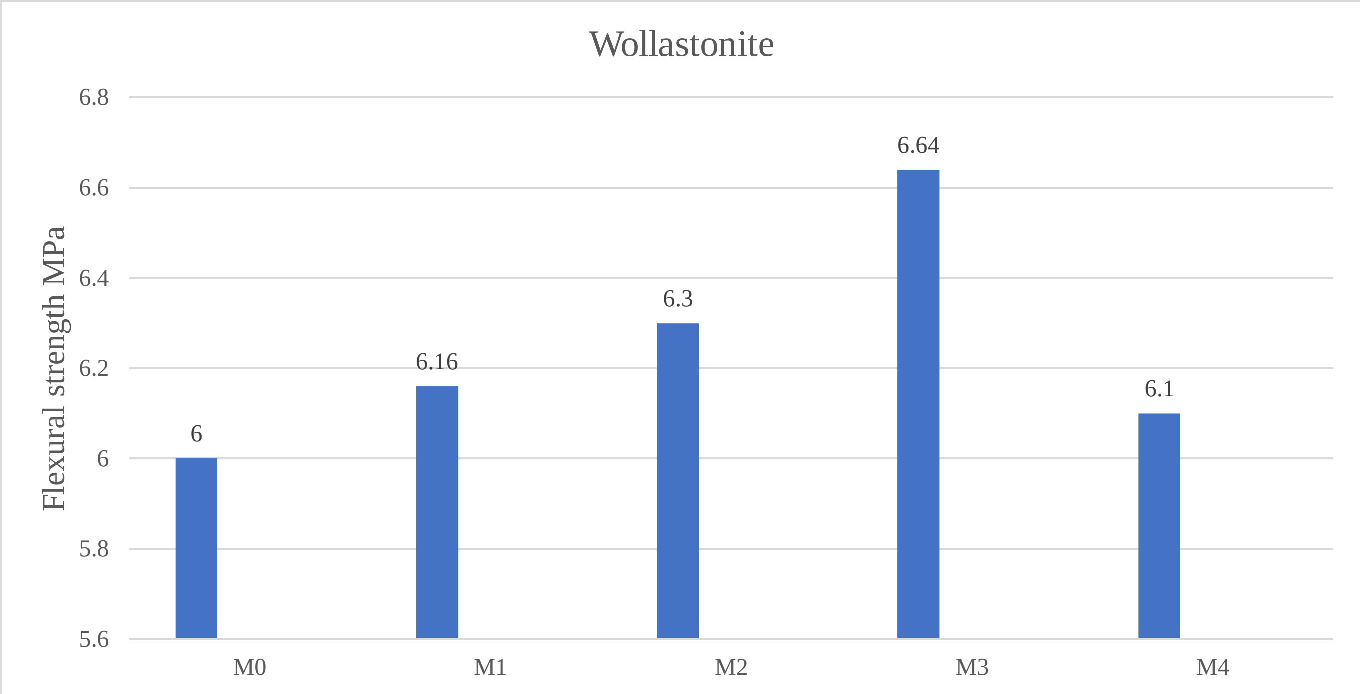

Figure 5: Relation between % wollastonite replacement and flexural strength

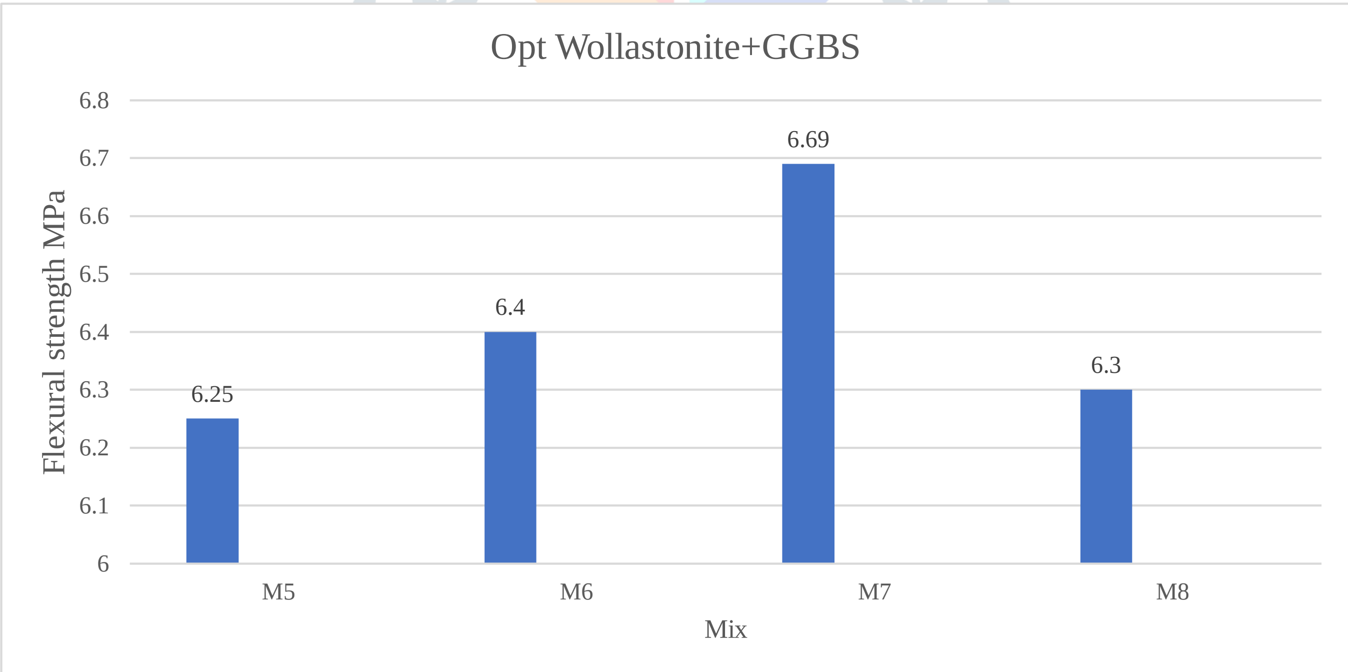

Figure 6: Relation between opt wollastonite(15%)+%GGBS replacement and flexural strength

Durability properties

Acid Attack

The concrete cubes of size 100mm were cured for a period of 28 days. After 28 days of curing of specimens, cube surfaces were cleaned and weighed. The specimens were immersed in a sulfuric acid(H_2SO_4) solution. The solution was checked periodically. After 28 days, the specimens were removed from the solution. The percentage of weight loss was determined and the percentage of strength loss was determined as shown in table 8. To conduct this test, 5% by volume of sulfuric acid was mixed with ordinary potable water.

Table 8: Mass loss and compressive strength after exposure to 5% dilute H_2SO_4 for month

Mixes	Compressive strength after 28 days of normal curing(MPa)	Compressive strength after 28 days of acid curing(MPa)	Reduction in strength(%)
Mix0	59	52.45	11.1
Mix1	62	58.9	5
Mix2	63.5	61	3.93
Mix3	65	62.8	3.38
Mix4	60	57.35	4.41
Mix5	61.5	59	4.09
Mix6	63	60.95	3.25
Mix7	66.5	63.4	4.66
Mix8	62	60.5	2.41

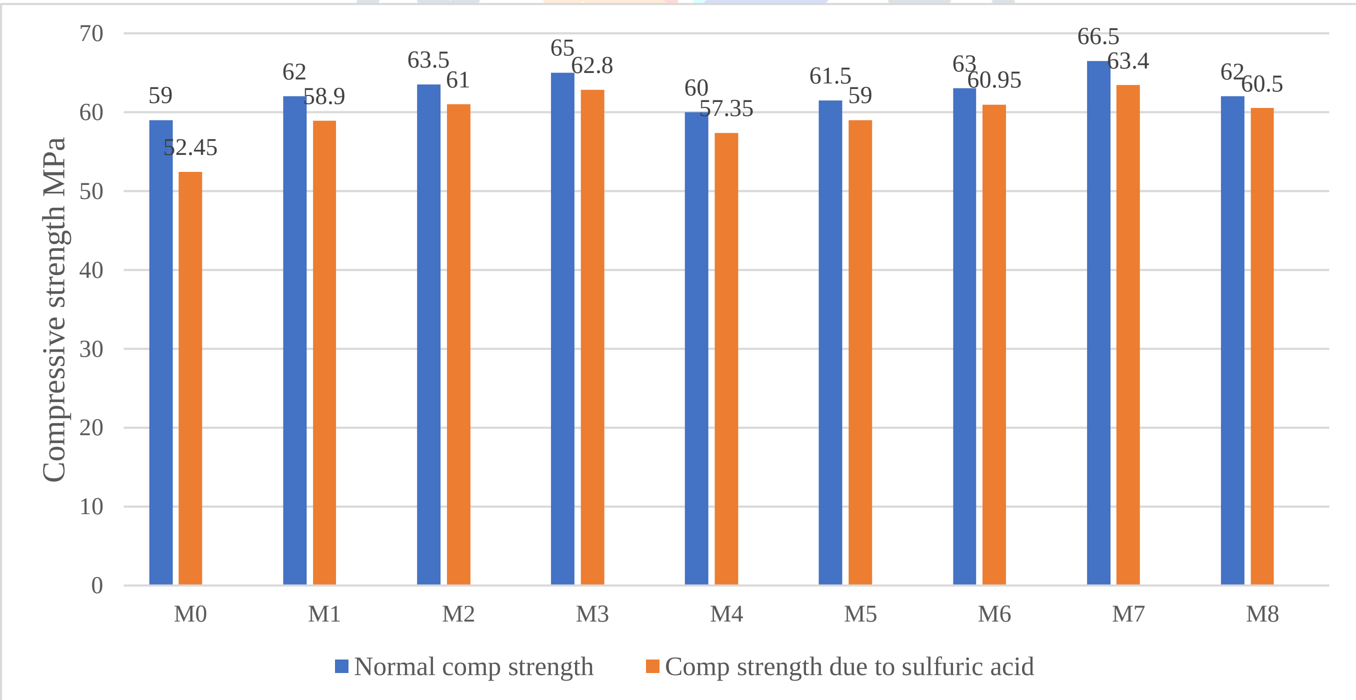

Figure 7: compressive strength of cubes after performing an acid attack

The above figure shows the graphical representation of the compressive strength of the concrete cubes after being immersed in the sulfuric acid solution for 28 days. It is found that the compressive strength of the control mix reduces by 11.1% whereas for mix 3 strength was reduced by 3.38% and for mix 7 the strength was reduced to 4.66%.

Sulphate Attack

Sulphate attack of concrete is a complex process, which includes physical salt attack due to salt crystallization and chemical sulphate attack from the soil, groundwater, or seawater. Sulphate attack can lead to expansion, cracking, strength loss, and disintegration of concrete. To perform this test the concrete cubes of 100mm were cast and cured for a period of 28 days. After 28 days of curing of specimens, cube surfaces were cleaned and weighed. The specimens were immersed in a magnesium sulphate solution. The solution was checked periodically. After 28 days, the specimens were removed from the solution. The percentage of strength loss was determined as shown in Table 8. To conduct this test, 5% by volume of magnesium sulphate was mixed with ordinary potable water.

Table 8: Mass loss and compressive strength after exposure to 5% dilute magnesium sulphate for a month

Mixes	Compressive strength after 28 days of normal curing(MPa)	Compressive strength after 28 days of magnesium sulphate curing(MPa)	Reduction in strength %
Mix 0	59	54	7.62
Mix 3	65	62.8	3.38
Mix 7	66.5	63	5.26

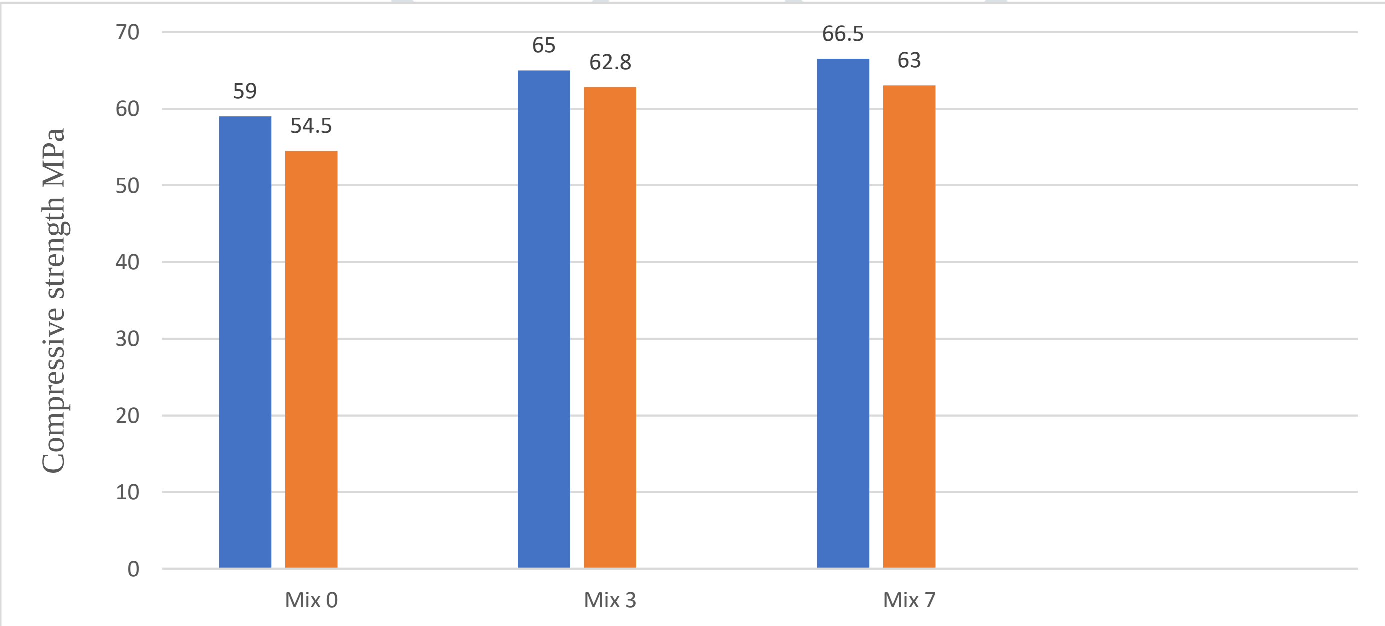

Figure 8: compressive strength of cubes after sulphate attack

Chloride Attack

When considering the durability of concrete, chloride attack is the most imminent enemy. It is responsible for almost 40% of the failure of concrete structures. In the presence of oxygen and water, chloride attack corrodes the steel reducing the strength of the structure's durability. To perform this test the concrete cubes of 100mm were cast and cured for a period of 28 days. After 28 days of curing of specimens, cube surfaces were cleaned and weighed. The specimens were immersed in a sodium chloride solution. The solution was checked periodically. After 28 days, the specimens were removed from the solution. The percentage of strength loss was determined as shown in Table 9. To conduct this test, 5% by volume of magnesium sulphate was mixed with ordinary potable water.

Table 9: Mass loss and compressive strength after exposure to 5% dilute magnesium sulphate for a month

Mixes	Compressive strength after 28 days of normal curing(MPa)	Compressive strength after 28 days of sodium chloride curing(MPa)	Reduction in strength %
Mix 0	59	56.6	4.06
Mix 3	65	63.2	2.79
Mix 7	66.5	64.5	3

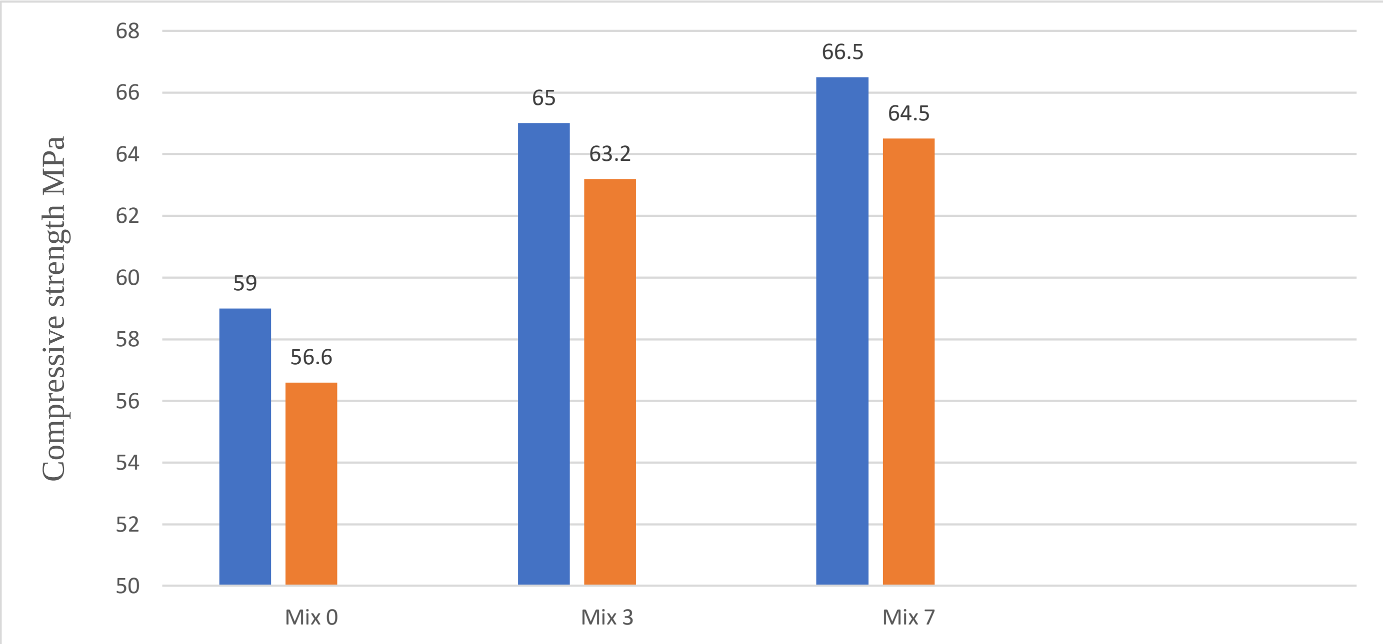

Figure 9: compressive strength of cubes after Chloride attack

V.CONCLUSION

Based on the above study, the following observations are made regarding the strength properties of concrete on partial replacement of cement by wollastonite and mineral admixture GGBS.

- As the 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 15% of wollastonite.
- The concrete mix with 15% wollastonite and 15% GGBS obtained the highest strength properties of concrete compared to all other mixes.
- Based on experimental results, it is observed that significant improvement in the strength properties of concrete with wollastonite and GGBS combination compared to wollastonite concrete mix.

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