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GGBS and Wollastonite Effects on the Properties of Concrete as Partial Cement Replacement

Shaik Mohammad Shoheb [a], M Maddilety[b]

[a] PG Student, Civil Department, Dr. K. V. Subba Reddy Institute of Technology, Kurnool, and 518218 , India
[b] Assistant Professor, Civil Department, Dr. K. V. Subba Reddy Institute of Technology, Kurnool, and 518218, India

A B S T R A C T

Every feasible way to reduce CO2 emissions is being developed in this era of widespread global warming, with the production of cement being one of the main sources of emissions. Many materials, including fly ash, GGBS, silica fume, wollastonite, and waste glass powder, are utilized in place of some cement in order to address this issue. Reducing environmental pollution can be achieved by substituting ground granulated blast furnace slag and wollastonite for some of the cement. A naturally occurring mineral, wollastonite is less expensive than cement.

The purpose of this work is to ascertain how the wollastonite-GGBS (W-GGBS) combination affects the durability and mechanical qualities of M30-grade concrete. We investigate the concrete's strength characteristics when wollastonite (5%, 10%, 15%, 20%) is added. If the ideal percentage of wollastonite replacement is maintained, then additional cement can be substituted with mineral admixtures, like GGBS (5%, 10%, 15%, 20%).

According to test results, using cement in place of 15% wollastonite produces better results than using the standard mixture. A mixture containing 15% GGBS and 15% wollastonite showed the biggest strength gain.

Keywords: GGBS, mechanical qualities, durability properties, wollastonite

INTRODUCTION

1.1 General

Concrete's strength, durability, and versatility make it a popular building material. Concrete is made up of three main ingredients: cement, water, and aggregates, which can be crushed stone, gravel, or sand. Concrete use and manufacture have a substantial negative influence on the environment, mostly because cement production produces carbon dioxide emissions. Significant amounts of energy are required for the production of cement, and this process also releases large amounts of greenhouse gases, such CO2, which exacerbate the issue of global warming. Furthermore, the removal of raw materials like sand and gravel that are needed to make concrete can have a detrimental effect on ecosystems, landscapes, and natural habitats. To address these problems, scientists are looking into ways to reduce the environmental impact of concrete by developing more environmentally friendly production techniques and including substitute ingredients such GGBS, fly ash, slag, and wollastonite powder. Additionally, by extending the life and energy efficiency of infrastructure and buildings, the use of concrete in construction can benefit the environment. It is becoming more and more crucial to develop environmentally friendly concrete production and use procedures as the demand for sustainable construction grows.

Adding supplemental cementitious materials (SCMs) to concrete is one way to lessen the environmental effect of the cement production process. SCMs are substances that, when used in the making of concrete, can partially replace regular cement. This will reduce the energy used and greenhouse gas emissions associated with the production of cement. Waste materials from industrial operations such as fly ash, slag, lime sludge, wollastonite, GGBS, and silica fume are examples of common SCMs. These substances can increase workability, strength, and durability while lowering the required cement content. Furthermore, by decreasing shrinkage and cracking, enhancing resistance to chemical assault and freeze-thaw cycles, and extending the lifespan of structures, the use of SCMs will enhance the long-term performance of concrete. The use of SCMs in the manufacturing of concrete has the potential to improve the long-term performance and resilience of concrete structures while reducing the environmental impact of building practices. Adding SCMs to conventional cement mixtures is known as ternary and quaternary binders, and they are alternative methods for enhancing concrete performance. Several investigations have been carried out to examine the microstructure, strength, and durability of quaternary concrete composites, taking into account the impact of various elements. Additionally, studies employing methods like digital image correlation have been done on the fracture parameters and effectiveness of concretes made using quaternary mixed cements.

More recently, research has been done on the impact of acrylamide in situ polymerization on the microstructure and mechanical characteristics of a particular quaternary system. In the current investigation, wollastonite powder and GGBS were combined to create a ternary blended mix..

1.2 Supplemental Cementations Materials

Wollastonite is a naturally occurring mineral that is created when silica and limestone mix in heated magmas. Wollastonite, which is chemically calcium metasilicate, has been shown to have chemically reinforcing properties and to be resistant to chemical attack even at high temperatures. Wollastonite is a mineral that is mostly composed of Si02 and CaO. Each component makes up about half of the mineral by weight percentage in a pure CaSi03.It is a highly modulus white mineral. It is used to improve the tensile strength of plastics and reduce shrinkage cracks in ceramic tiles. Increasing the strength and longevity of concrete is one of the main advantages of adding wollastonite powder to it. Because of the special needle-like structure of wollastonite powder, concrete is strengthened and becomes more resilient to damage and cracking. Furthermore, the high aspect ratio of wollastonite powder indicates that it has a significant surface area relative to its volume. It therefore functions as a useful filler material that can assist reduce the quantity of cement used in the manufacturing of concrete, consequently reducing costs and lowering the impact on the environment. Increasing the workability of concrete is another advantage of adding wollastonite powder. Wollastonite powder is a fine substance that is simple to include into concrete mixtures, increasing their flow ability and lowering the amount of water needed. As a result, handling concrete may be easier, requiring less manpower and time to finish building tasks. Additionally, wollastonite powder can enhance the thermal characteristics of concrete. Its low thermal conductivity can aid in lowering the amount of heat lost from buildings and other structures. Lower energy expenses and a more comfortable home or working environment may result from this.

Wollastonite powder can also enhance the chemical characteristics of concrete. Because of its high pH, it may be able to inhibit the growth of bacteria and other microbes that could harm the concrete. This may lengthen the concrete's lifespan and lessen the need for expensive maintenance or replacements. All things considered; wollastonite powder is a useful addition to concrete that can enhance its qualities in a number of ways. Strength, workability, and thermal and chemical qualities can all be improved, making it a more adaptable and efficient material for a range of building uses. Its use in concrete can also assist lower costs and lessen environmental effect, making it an environmentally beneficial and sustainable option for contractors and builders.

Wollastonite is typically found as a common component of impure limestone that has undergone thermal metamorphism. However, it can also arise from contamination in invasive igneous rock or from metamorphism in contact with altered calcareous deposits. The majority of these incidents are caused by the reaction between silica and calcite that results in the release of carbon dioxide.

$CaCO_3 + SiO_2 \rightarrow CaSiO_3 + CO_2$

Important elements responsible for market expansion:

1. Greater suitability for rubber and plastic applications.

2. Wollastonite is becoming more and more well-liked as an affordable reinforcing material for ceramics and white ware.

3. Businesses in the market for wollastonite powder are expanding their production

capabilities.

4. Growing construction activity globally

Major Market Segments Covered:

By Application

- Polymers
- Paints
- Friction Products
- Construction
- Metallurgy
- Others

A byproduct of the blast furnaces used to produce iron is called ground granulated blast furnace slag, or GGBS. They run at roughly 1500 degrees Celsius and are supplied with a precisely regulated blend of limestone, coke, and iron ore. Iron and the leftover components from a slag that floats on top of the iron are all that remain of the iron ore. This slag must be quickly quenched in a lot of water if it is to be used in the production of GGBS. It is periodically tapped off as a molten liquid. The process of quenching yields granules that resemble coarse sand while optimizing the cementitious qualities. After being dried, the granulated slag is ground into a fine powder. Other names for it include "GGBS" and "Slag cement."… ………………...

Because GGBS functions as pozzolans, when it is combined with Portland cement, it forms a hardened cement that has more small gel pores and fewer larger capillary pores than regular Portland cement. This gives the cement greater durability and reduced permeability. Additionally, it has less free lime, which when present generates ettringite or efflorescence and increases the chemical stability of the cured cement.

Advantages of GGBS

- ✓ Reduced thermal cracks due to lower heat of hydration.
- ✓ Reduced shrinkage cracks.
- ✓ Improved workability and smooth finish.
- ✓ Improved cohesion.
- ✓ Less susceptible to chemical attacks.
- ✓ Higher long-term strength.
- ✓ Higher flexural strength.
- ✓ Improved durability and hydration.

The experimental effort done to ascertain the impact of partially substituting GGBS and wollastonite for OPC is presented in this publication. Investigated include the tensile splitting strength, slump test, compacting factor test, compressive strength, and durability test for acid assault. Additionally, the ideal wollastonite and GGBS content is established.

………………… **Table 1.1 Composition of Wollastonite and GGBS**

Binder	**Wollastonite (%)**	**GGBS (%)**
SiO2	46-52	32-38
CaO	45-48	40-45
Fe2O3	0.75	0.37
Al2O3	3-5	13
MgO	0.88	8
LOI	4.85	5.55

2. MATERIALS USED

2.1 Cement:

Ordinary grade 43 manufactured from a batch of JSW cement, as specified in IS: 12269-1987 (OPC), was used in this work as Portland cement for research. There are no lumps and it is fresh. Cement should be stored carefully to avoid moisture-induced loss of its properties.

The cement used is JSW Cement, especially Standard Portland Cement (OPC 43 Review).

2.2 Fine Aggregate:

It is normally the aggregate that passes through a 4.75 mm IS screen and only coarse particles are allowed in the standards. On the basis of fine aggregate, it will be defined as follows:

1. Natural Sand - Aggregate generated by the natural disintegration of rocks and deposited by streams or glacial constructions

2. Stone sand - fine aggregate generated by breaking hard rocks.

3. Gravel sand — fine aggregate generated by crushing natural gravel.

Fine aggregates are categorized into coarse sand, medium sand and fine sand according to their particle sizes. IS standards split fine aggregates into four groups based on their grade, from grading zone 1 to grading zone 4.

The biggest aggregate in the four grading regions is 20 mm with regular grading. The specific gravity of the coarse aggregate utilized is 2.73. Sieve examination of both coarse and fine aggregates conforms with IS10262 standard. Develop steadily from Zone-1 grade to Zone-4 grade. Depending on the gradation area of the fine aggregate, 90% to 100% passes through the 4.75 mm IS sieve and 0% to 15% passes through the 150 micron IS sieve.

2.3 Coarse Aggregate:

It is the majority of the residual aggregate. The 4.75mm IS screen is merely made of a finer material than necessary. The following definitions of coarse aggregate vary by location:

1. Unbroken stone or gravel, which results from stone's natural disintegration

2. Crushed Stone or Gravel: Stone or gravel that has been crushed.

3. Semi-crushed stone or gravel is a combination of the first two aggregates mentioned. Depending on its size, coarse aggregate can have diameters ranging from 40 mm to 20 mm, 16 mm, and 12.5 mm. For instance, material that passes through the 20 mm IS sieve is typically referred to as graded aggregate with a nominal size of 20 mm.

Large aggregates are aggregates that typically fit through large sieves. A 20 mm huge aggregate, for instance, is one that typically passes through the 20 mm IS filter and stays above the 10 mm IS sieve.

2.4 Wallastonite:

Wollastonite is a calcium silicate (CaSiO3) mineral that occasionally has trace quantities of manganese, iron, and magnesium in place of calcium. Usually, it's free. It develops when dolomite or impure limestone is heated to high pressure and is in contact with metamorphic rocks or siliceous fluids like skarn. Garnet, vesuvite, diopside, tremolite, epidote, plagioclase, pyroxene, and calcite are among the associated minerals. Additionally, organisms in weak rocks or the process of metamorphism in shifting limestone beds can generate silica. It usually results from the following reaction that takes place when carbon dioxide is lost between calcite and silica:

$SiO_2 + CaCO_3 \text{--->} CaSiO_3 + CO_2$

Skarn can also contain wollastonite. Silica is formed in the sand as a result of calcium ions moving outward during diffusion reactions that change the limestone in sandstone by dykes.

Although wollastonite is one of the silicates that grows the fastest, carbon monoxide can be expensive. Wollastonite is added to the mineralization mud of organic carbon. In addition to increasing greenness and firing, preserving shine throughout firing, enabling faster firing, and lowering cracks, fissures, and glaze defects, wollastonite also minimizes shrinkage and gas generation during ceramic burning. Wollastonite is chemically resistant, stable at high temperatures, and improves the strength and tensile strength of composite materials, much like asbestos. Some sectors, such the manufacturing of mineral wool insulation or domestic items, use wollastonite with varying concentrations of impurities. By using Wollastonite in cement, it was claimed in 2019 that the material could "reduce the total carbon monoxide of precast concrete by 70%", cool the slag, and shield the molten metal surface during the metal casting process. High Temperature Thermal and Dimensional Stability Wollastonite and the polymers it is added to have better adhesion when surface treatments are applied.

2.5 Water

Water used in construction must have the following properties:

1. There should be no oil, acid, alkali or other organic or inorganic contaminants.

2. It should not include metal, plant debris or other elements that would harm the stone and should be appropriate for drinking

2.6 Admixture

Conplast WL Xtra is a dark brown liquid with a polymer base for cement dispersion that mixes well with water and disperses uniformly. It lessens the amount of water needed to achieve the necessary workability and minimizes bleeding and segregation. It conforms to IS:2645-2003.Dosage: For 50 kg of cement, 200 ml is the ideal dosage.

Benefits and Features:

New Technology: Concrete with superior performance is produced by a novel chemical. Fit for anysolid grade, even higher grades.

Corrosion resistance: Complies with Japanese code JIS Z1535 (modified) for the first class of integral water proofing products.

Superior Strength: Owing to enhanced cement particle dispersion and improved degree of hydration, this material exhibits superior strength in comparison to its control.

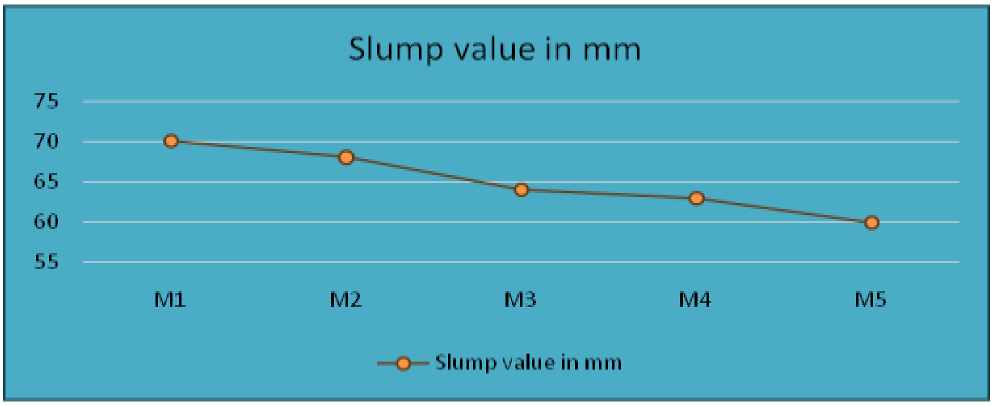
Cohesive Mix: Enhances the concrete's cohesion and workability.

Durability: Increases durability by reducing concrete permeability and strengthening steel's resistance to corrosion.

TEST RESULTS

Table no 3.1 Slump Cone values

MixType	Wollastonite (%)	GGBS (%)	Slump value in mm
M1	0	0	70
M2	5	5	68
M3	10	10	64
M4	15	15	63
M5	20	20	60



Graph 1: Slump Cone values

Table no 3.2: Mix proportion of M30

Grade	M30
Proportion	1:2.1: 3.57
W/C ratio	0.43
Cement	341 Kg/m^3
Fine Aggregate	732 Kg/m^3
Coarse Aggregate	1219 Kg/m^3
Water	147 Kg/m^3
Chemical admixture	3.41 Kg/m^3

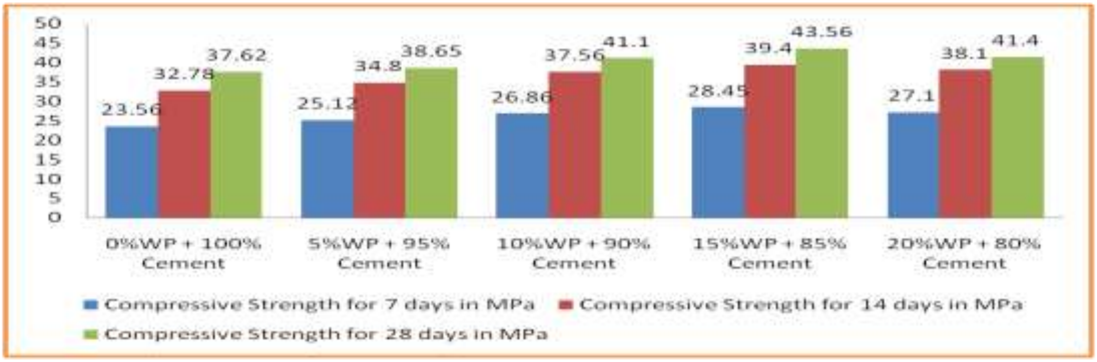
An experimental study was conducted by mixing M30 quality concrete. Preparation of concrete mix for M30 grade concrete as per IS:10262-2019. Four mixtures were prepared in which 5%, 10%, 15% and 20% wollastonite was added to the cement, respectively. It was determined that maximum strength was achieved by replacing the concrete by 15%. For this reason, the replacement of cement with 15% wollastonite was kept constant and the samples were tested by replacing the cement with additional minerals (such as 5%, 10%, 15% and 20% GGBS). A water/cement ratio of 0.43 was used for all mixtures throughout the study.

The Compressive Strength, Split Tensile Strength& Flexural strength results of M30 grade concrete after 7^{th}, 14^{th} and 28^{th} days curing are tested in the laboratory. The results are tabulated and graphs are represented below.

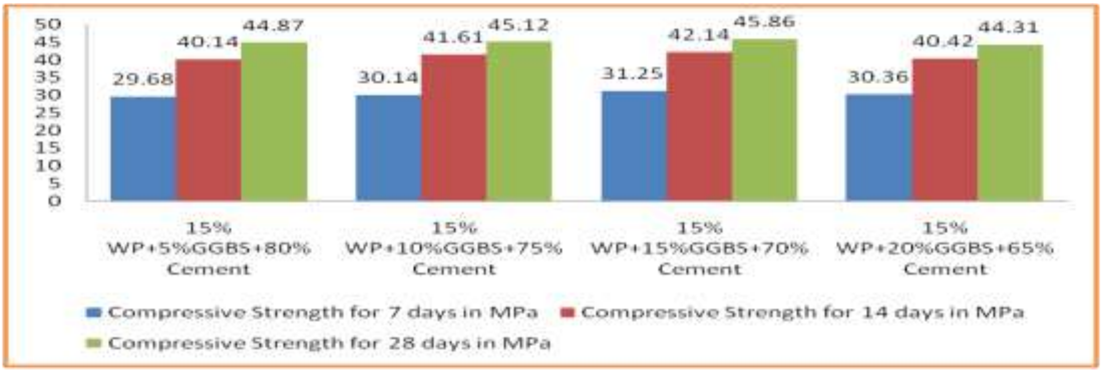
Table no 3.3 Test results of Compressive Strength for 7,14 & 28 days for M30

Mix % Replacement	Compressive Strength for 7 days in MPa	Compressive Strength for 14 days in MPa	Compressive Strength for 28 days in MPa
0%WP + 100% Cement	23.56	32.78	37.62
5%WP + 95% Cement	25.12	34.80	38.65

10%WP + 90% Cement	26.86	37.56	41.10
15%WP + 85% Cement	28.45	39.40	43.56
20%WP + 80% Cement	27.10	38.10	41.40
15% WP+5%GGBS+80% Cement	29.68	40.14	44.87
15% WP+10%GGBS+75% Cement	30.14	41.61	45.12
15% WP+15%GGBS+70% Cement	31.25	42.14	45.86
15% WP+20%GGBS+65% Cement	30.36	40.42	44.31



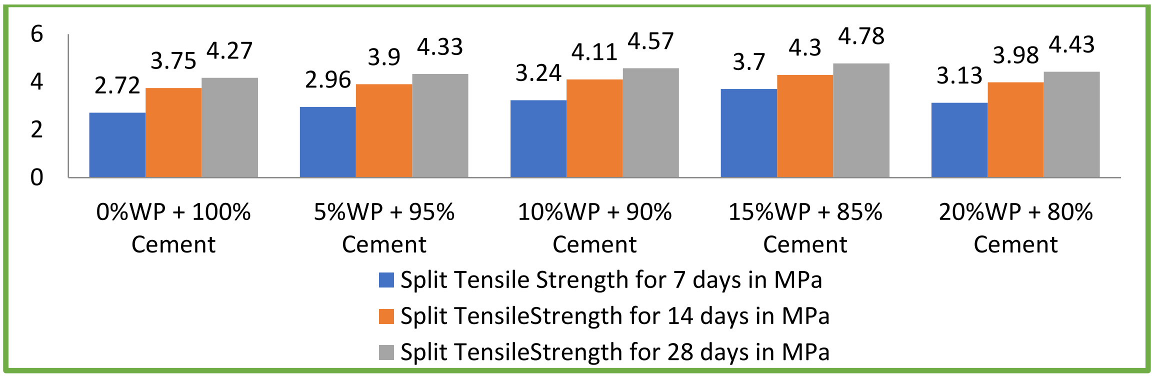
Graph No 2 Development of Compressive strength after curing 7, 14& 28 days for M30



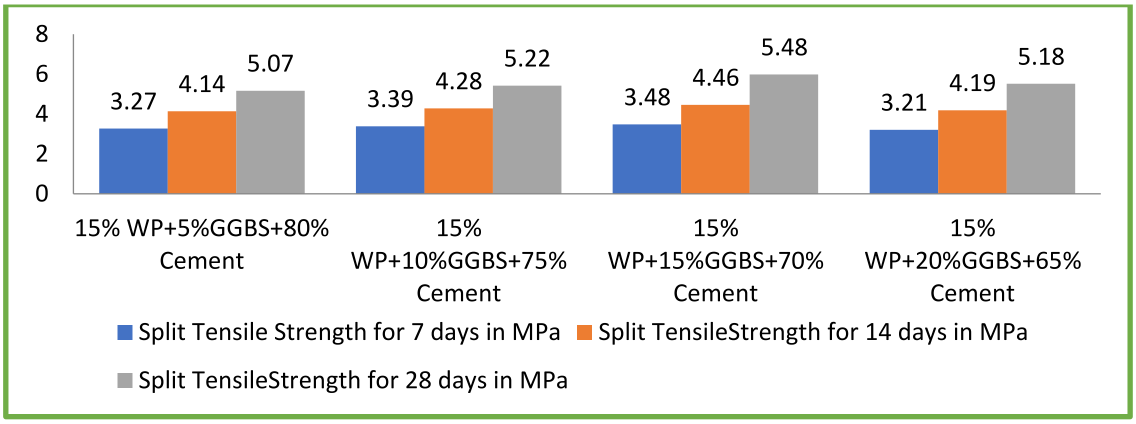
Graph No 3 Relation between optimum wollastonite (15%) +%GGBS replacement and Compressive strength

Table no 4 Test results of Split Tensile Strength for 7, 14 & 28 days for M30

Mix % Replacement	**Split Tensile Strength for 7 days in MPa**	**Split TensileStrength for 14 days in MPa**	**Split TensileStrength for 28 days in MPa**
0%WP + 100% Cement	2.72	3.75	4.27
5%WP + 95% Cement	2.96	3.90	4.33
10%WP + 90% Cement	3.24	4.11	4.57
15%WP + 85% Cement	3.70	4.30	4.78
20%WP + 80% Cement	3.13	3.98	4.43
15% WP+5%GGBS+80% Cement	3.27	4.14	5.07
15% WP+10%GGBS+75% Cement	3.39	4.28	5.22
15% WP+15%GGBS+70% Cement	3.48	4.46	5.48
15% WP+20%GGBS+65% Cement	3.21	4.19	5.18



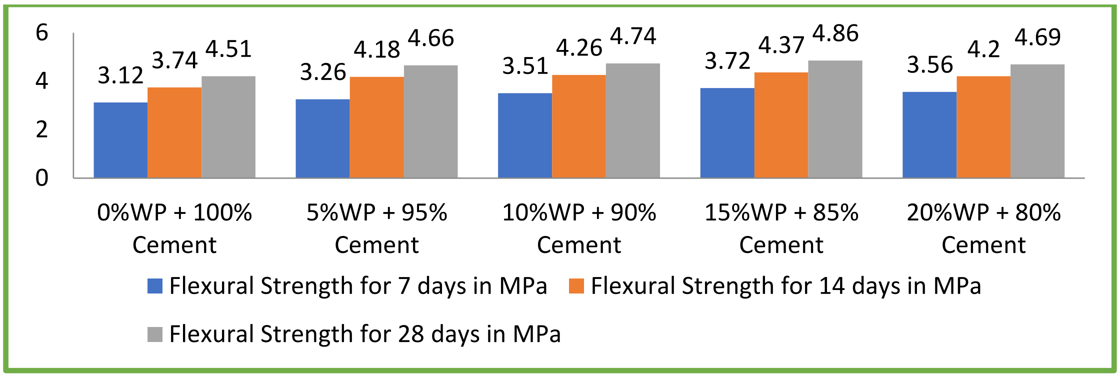
Graph No 4 Development of Split Tensile strength after curing 7,14 & 28 days for M30



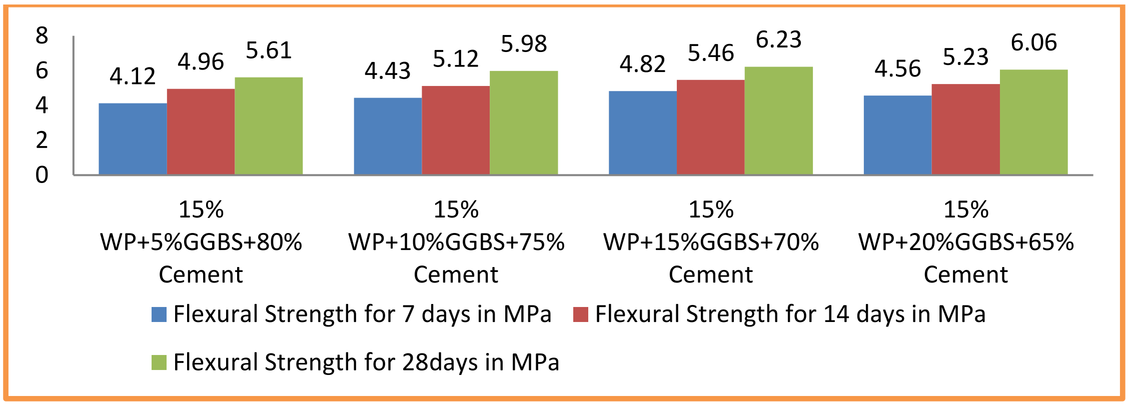
Graph No 5 Relation between optimum wollastonite (15%) +%GGBS replacement and Split Tensile strength

Table no 5 Test results of Flexural Strength for 7, 14 & 28 days for M30

Mix % Replacement	**Flexural Strength for 7 days in MPa**	**Flexural Strength for 14 days in MPa**	**Flexural Strength for 28 days in MPa**
0%WP + 100% Cement	3.12	3.74	4.51
5%WP + 95% Cement	3.26	4.18	4.66
10%WP + 90% Cement	3.51	4.26	4.74
15%WP + 85% Cement	3.72	4.37	4.86
20%WP + 80% Cement	3.56	4.20	4.69
15% WP+5%GGBS+80% Cement	4.12	4.96	5.61
15% WP+10%GGBS+75% Cement	4.43	5.12	5.98
15% WP+15%GGBS+70% Cement	4.82	5.46	6 .23
15% WP+20%GGBS+65% Cement	4.56	5.23	6.06



Graph No 6 Development of Flexural strength after curing 7, 14 & 28 days for M30



Graph No 7 Relation between optimum wollastonite (15%) +%GGBS replacement and Flexural strength

It was found that when cement was replaced with 15% wollastonite, the strength properties increased and then decreased. The maximum Compressive strength of the 15% wollastonite mixture is 43.56 N/mm^2, which is 15.78% higher than the reference mixture whereas Tensile strength is 4.78 N/mm^2 which is 11.94% higher than reference mixture and Flexural strength is 4.86 N/mm^2 which is 7.76% higher than reference mixture.

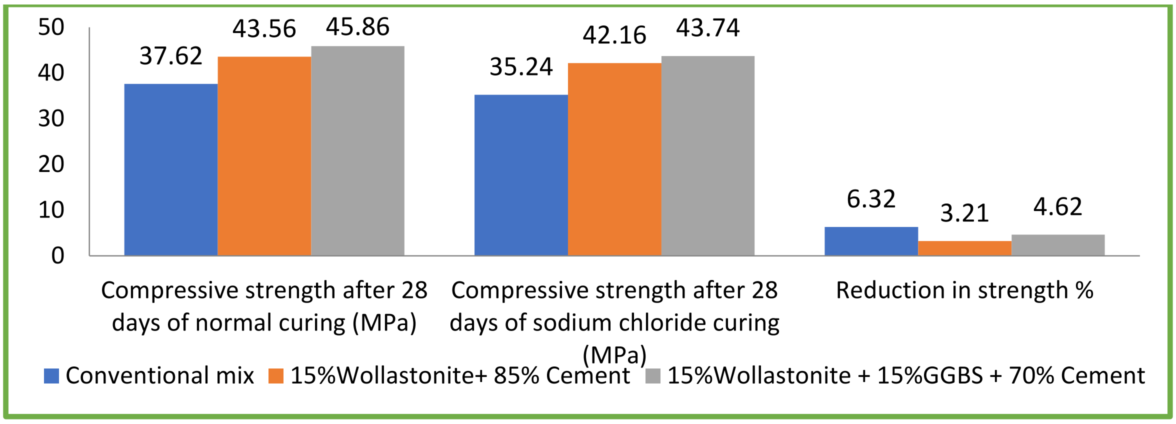
Among all GGBS substitutes, the highest strength is achieved when mixed with grade M30, which contains 15% wollastonite and 15% GGBS. As the GGBS content of concrete increases, its strength properties first increase up to 15% and then decreases. The maximum strength is achieved when the wollastonite content is 15%, and 15% GGBS reaches a compressive strength of 45.86N/mm^2 which is 21.90% higher than the composite material whereas tensile strength of 5.48N/mm^2 which is 28.33% is higher than the composite material and flexural strength of 6.23N/mm^2, which is 38.13% higher than the composite materials.

DURABILITY TEST

The most immediate threat to the longevity of concrete is chloride assault. It accounts for over 40% of concrete structural failures. Chloride attack weakens the steel's resistance to deterioration in the presence of oxygen and water, hence decreasing the structure's longevity. Concrete cubes measuring 150 mm were cast and allowed to cure for a total of 28 days in order to conduct this test. Specimens were allowed to cure for 28 days before cube surfaces were cleaned and weighed. The specimens were submerged in a sodium chloride solution made by mixing 50 liters of distilled water with 5% sodium chloride salt (by volume of water). Periodically, the solution was examined. The specimens were taken out of the solution after 28 days. Table displays the percentage of strength reduction that was calculated.

Table 6 Mass loss and compressive strength after exposure to 5% sodium chloride 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 %**
Conventional mix	37.62	35.24	6.32
15%Wollastonite+ 85% Cement	43.56	42.16	3.21
15%Wollastonite + 15%GGBS + 70% Cement	45.86	43.74	4.62



Graph No 8 compressive strength of cubes after Chloride attack

Conclusions

Based on the above research, the following analysis was carried out on artificial concrete in which cement was partially replaced with wollastonite and the mineral additive GGBS.

1.As the wollastonite ratio in the Concrete changes, its workability decreases.

2.It was found that the maximum strength in the total percentage of cement modified with wollastonite occurred at 15% wollastonite.

3.Compared to other mixtures, the highest concrete properties were obtained with concrete mixtures containing 15% wollastonite and 15% GGBS.

4.According to the test results, it was determined that the strength of the concrete combined with wollastonite and GGBS increased better than the wollastonite concrete mixture.

5.It is seen that the use of 15% wollastonite increases the compressive strength by 15.78%, splitting tensile strength by 11.94% and bending strength by 7.76% compared to conventional concrete.

6.Compared to normal concrete, it is seen that the use of 15% wollastonite and 15% GGBS increases the compressive strength by 21.90%, splitting tensile strength by 28.33% and bending strength by 38.13%.

7.When half replaced by 15% wollastonite cement and 15% GGBS cement, it has very good resistance to chloride attack compared to conventional concrete.

References

1. Misra, A., Chad, Y.B., Rana, A., Misra, P., and Csetenyi, L. (2015). Research on the durability of wollastonite-containing concrete. 726–734, Journal of Cleaner Production, 87.
2. In 2014, Rughooputh, R., and Rana, J. Adding ground-granulated blast furnace slag to concrete in place of some of the cement. Journal of Engineering and Applied Sciences: Emerging Trends, 5(5), pp. 340-343.
3. In 2017, Ravichandran, A., Muthadhi, A., and Ravram, M. research on the best ways to use GGBS in concrete. Journal of Innovation Science and Technology, 2(5), 773–779.
4. Misra, A., Gupta, R.C., Csetenyi, L., Gahlot, V., and Arora, A., together with P. Kalla, (2013). Investigations on the mechanical properties and durability of a combination of fly ash and wollastonite in concrete. Building Materials and Construction, 40, pp. 1142-1150.
5. IS 2386:1963 Section III pertains to the aggregate's bulk density, specific gravity, and water absorption.
6. Anurag Mishra, Pawan Kalla, and Aditya Rana "Studies on the durability of concrete containing wollastonite." Elsevier, Journal of Cleaner Production, 2014.
7. Experimental Study on Mechanical Properties of Concrete Including Wollastonite and Ground Granulated Blast Furnace Slag as A Partial Replacement of Cement, Vijay Bhudiya, Abbas Jamani, 2020 Journal of Engineering and Technology: International Research, Volume 7, Issue 6, pages 4559–4567
8. S. Arivalagan. (2014). sustainable research on concrete using GGBS in place of cement. Civil Engineering Journal of Jordan, 159(3147), pp. 1–8.

9. "Investigation on pastes and mortars of Portland cement admixed with wollastonite and micro silica," by G.D. Ransinchung and Brind Kumar. Journal of Civil Engineering Materials 2010 ASCE 39(12):25–31.
10. Indian Standard Code of Practice, 1970; IS: 383 (Specification for >4.75mm and fine particles from natural sources for concrete).
11. "IS 10262-2009, Recommended Guidelines for Concrete Mix Design" Standards, Bureau of Indian Standards, New Delhi, India, 2009.
12. "IS 8112:1989, Specification (First Revision), Bureau of Indian Standards, New Delhi, India, 1989" describes grade ordinary Portland cement.
13. Bureau of Indian Standards, Manak Bhavan, 9 Bahadur Shah Marg, New Delhi-110002; IS: 4 56-2000, Plain and Reinforced Concrete Code of Practice.
14. BIS 383: 1970 Natural sources of coarse and fine aggregate for concrete, 9th Revision, B IS, New Delhi, 1970.
15. "Concrete technology," Shetty M.S., S.Chand& Company Limited, 2009
16. Satya Sai Trimurty, V.S. Reddy E3S Web of Conferences, 184, 01082 (2020) [4] Naidu, K., Seshagiri Rao, M.V., and Shrihari, S. "Influence of wollastonite - GGBS on properties of ternary blended self-compacting concrete," M. D. Gouse Mohiuddin, Venu Malagavelli, and Praveen Kumar Balguri, 2022.
17. Shikant Sharma, Sandeep Panchal, Amrit Kumar Roy, and Mohd. Mohsin Khan."Performance Comparison of Fly ash and Wollastonite micro-fiber in obtaining self-compacting concrete mixes." Materials Today Proceedings, Vol. 1, pp. 1-6. Vol. 8, pp. 137–145, International Journal of Civil Engineering and Technology (IJCIET)
18. Research on Self-Compacting Geopolymer Concrete Including Flyash, GGBS,Wollastonite, and Graphene Oxide was conducted by Vishnu, N.; Kolli, R.; and Ravella, D.P.
19. Supraxia Xavier Lopes and R. S. Chikkanagoudar (2020) Wollastonite as a Partial Cement Replacement and Its Impact on the Mechanical and Durability Properties of Concrete the International Research Journal of Engineering and Technology (IRJET) Volume 07 Issue 08 | August 2020 e-ISSN: 2395-0056 p-ISSN: 2395-0072; www.irjet.net
20. "Mechanical properties of micro and sub-micron wollastonite fibers in cementitious composites," Dey V, Kachala R, Bonakdar A, and Mobasher B (2015), Construction and Building Materials, Vol. 82, pp. 351 - 359.
21. "Strength characteristics and microstructural properties of cement mortars incorporating synthetic wollastonite produced with a new technique" Hasan Erhan Yucel, Sumeyye Ozcan, July 2019. Elsevier Ltd. is the publisher.
22. KannulaMohankrishna Reddy and K. V. S. Gopala Krishna Sastry (2016). utilizing wollastonite-silica fume and wollastonite-flyash to test the strength qualities of concrete Vol. 6, issue 5, October 2016, 1–12, International Journal of Civil, Structural, Environmental, and Infrastructure Engineering Research and Development (ijcseierd), issn(p): 2249–6666; issn(e): 2249–7988.
23. Mr Kartik Patel (2019) Result of Wollastonite Then Ggbs by Way Of Part Paste Extra On The Assets Of Concrete, March 2019, Volume 6, Issue 1, International Journal of Research and Analytical Reviews, www.ijrar.org (E-ISSN 2348-1269, P- ISSN 2349-5138)