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Impact of GGBS and Wollastonite as Partial Cement Replacement on Concrete's Properties

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Abstract - Every feasible way to reduce CO_2 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 M40-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.

Key Words: GGBS, mechanical qualities, durability properties, wollastonite

1.INTRODUCTION

The most prevalent and harmful environmental problem is global warming. Greenhouse gasses, particularly carbon dioxide (CO2), are the primary cause of these phenomena. Finding a way to lessen carbon footprints is a new scientific trend. on the planet. A difficult yet essential task for sustainable development in the future. Nearly 195 nations signed the Paris Agreement in order to accomplish the aforementioned objectives. According to the Paris Agreement, global temperatures should drop by 1.5 to 2 degrees Celsius, which means CO2 emissions should drop by 45% by 2030. We must identify alternative sources in order to address environmental challenges. We may also conclude from numerous general studies that adding mineral admixtures to concrete makes it more resilient to deterioration.

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.

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 flowability 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.

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.

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.

Significance of Research

Supplementary cementitious materials can be added to concrete to improve a variety of properties. These can include purely physical effects related to the presence of very fine particles or physical-chemical effects related to mineral admixture reactions, which modify the pore structure. Incorporating additional cementitious material into concrete increases its strength, longevity, and affordability. One pozzolanic mineral that occurs naturally and can be utilized in concrete is wollastonite. The world's top environmental concern today is solid waste management due to the growing amounts of waste materials and industrial byproducts. The use of trash and byproducts for recycling has grown in popularity as a disposal option due to the lack of landfill space and the rising expense of disposal. Numerous waste products and byproducts are produced. The characteristics of cement-based materials are impacted differently by each of these waste products. In addition to making concrete more affordable, the use of these components also helps to lessen waste issues. An industrial by-product called ground granulated blast furnace slag (GGBS) can be used to partially substitute cement in concrete. The effects of using mineral admixtures and wollastonite on concrete were examined in this paper. The investigation's findings will be utilized to determine the mix proportions for concrete and construction uses.

2. LITERATURE REVIEW

The objective of literature review is to collect published information from numerous study publications. We choose valuable data for research investigations using data analysis.

The slump, compressive, and tensile strengths of M20, M30, and M40 grade concrete with partial substitution of wollastonite and GGBS cement were investigated by

Vijay Bhudiya and Abbas Jamani [1]. In comparison to the control mixture, the compressive strength of the concrete increased from 15% to 20% when a portion of the cement was substituted with 20% GGBS and 20% wollastonite. Concrete becomes more durable as its GGBS content rises.

Kartik Patel [2] Carbon dioxide emissions and the loss of natural resources are two significant developments that have an impact on cement production. Certain natural or waste minerals used in concrete, such as wollastonite, fly ash, GGBS, silica fume, and waste glass powder, can be substituted to address this issue. Pollution to the environment can be decreased by substituting wollastonite and ground granular blast furnace slag (GGBS) for part of the cement. Rajasthan's Udaipur belt in India is a fantastic location to get inexpensive gemstones. This study aims to investigate the effects of w-GGBS (wollastonite) combinations on the workability and durability of M50 class concrete. We investigate the strength of concrete with 5%, 10%, 15%, and 20% wollastonite addition. The optimal wollastonite percentage that corresponds to the stone's highest strength will be determined. To replace more cement while keeping the targeted wollastonite replacement percentage (5%, 10%, 15%, 20%), additional minerals like GGBS are added. The test indicates that it is more effective to use cement rather than 15% wollastonite in composite structures. The strongest blend was found to contain 15% GGBS and 15% wollastonite.

Pammi Divya et al.[3] One business from the product is fly ash. The materials are used as binders, but wollastonite is a mineral that can be turned into cement and ground into fine powder. The mixture is designed to provide the required workability of M40 class concrete. It was noted that workability decreased and compressive strength increased when wollastonite and fly ash were used instead of cement. Addition of fly ash and silica reduced workability, but workability was within the limit when 50% cement, 30% fly ash and 20% silica were used.

GGBS is used instead of cement by **Dr. N. Vinod Babu and G. Hymavathi [4],** increasing the cube's strength and lowering pollution to the environment. The GGBS application rate in this survey is 10%, 20%, 30%, 40%, and 50% for M20 and M30 grades. In comparison to the control combination, it yields greater values, such as 10%, 20%, and 30%.

A study by **MD Gouse Mohiuddin et al. [5]** studied the use of GGBS and wollastonite as a good alternative to cement in M30 class self-compacting concrete. Evidence suggests that grade varies for wollastonite. Good results are achieved when the GGBS content reaches 15%.

Masthanvali, K. et al. [6] He conducted a study on concrete modified with 10% wollastonite and 15% slag The results showed that the compressive strength was 46.18 N/mm2 and the tensile strength was 3.09 N/mm2. Flexural strength is 46.18 N/mm2 Strength is 3.41 N/mm2 When 10% silica limestone and 10% silica fume are used as cement, the compressive strength is 47.20 N/mm2 and the tensile strength is 3.19 N/. mm2 and bending strength is 3.43 N/mm2. According to the test results, it is seen that the quality properties of cement containing a mixture of silica limestone and silica powder vary significantly depending on the mixture of silica limestone and fly ash.

Sharma Aman [7] The best wollastonite concrete mix was evaluated, and the concrete mix was compared with the concrete, in an experiment where different attributes of concrete, such as strength and durability, were examined, such as two types of acid assault and porosity test. Several varieties of wollastonite were utilized in this investigation in place of some cement. The study found that when wollastonite was put to concrete in greater amounts, the acid effects grew. Ultimately, 15% wollastonite was added to the mixture to bring the concrete's strength to its maximum. Concrete loses strength when the amount of WP increases. As wollastonite content rises, concrete's performance falls in comparison to the composite material.

Wahab and associates[9]. Compressive, flexural, drying shrinkage, and first hardening tests were performed. Wollastonite raises the flexural strength and compressive strength to 45% and 28%, respectively, when 20% of the sand is replaced with it. The first time, this results in a 60% delay. After 28 days, the flexural and compressive strengths of the cement with a 30% wollastonite addition dropped by 17% and 35%, respectively. Wollastonite powder strengthens the material's resistance to dry shrinkage.

3. MATERIALS

A mixture of cement or binder is added to materials or components to fill the gaps left by assembly and joints to make concrete. This experiment aims to ascertain how the wollastonite-GGBS (W-GGBS) combination affects the mechanical characteristics and longevity of M40 standard concrete. We looked at the strength of concrete that had 5%, 10%, 15%, and 20% wollastonite added. Increased cement can be substituted with mineral materials such as GGBS (5%, 10%, 15%, 20%), provided that the wollastonite replacement percentage stays constant. The primary components utilized in this investigation are water, fine and coarse aggregate, wollastonite-GGBS, and cement. High-quality materials that meet IS: 383-2016 standards, Conforms to IS: 383-2016 Water [Portable], Coarse Aggregate, Wollastonite-GGBS

- Class 43 Common Portland Cement, adhering to IS: 269-2015
- Fine Aggregate, adhering to IS: 383-2016
- Coarse Aggregate, according to IS: 383-2016
- Water [Portable]
- Wollastonite & GGBS
- Super plastisizer Conplast wl xtra

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4. EXPERIMENTAL INVESTIGATION

Normal Consistency of Cement	34%
Setting Time of Standard Cement	Intial -37 min Final - 562 min
Specific Gravity Of Cement	3.10
Fineness Test of Cement by Sieve Analysis	97%
Soundness of Cement	3 mm
Fineness Modulus of Fine Aggregate	4.07
Fineness Modulus of Coarse Aggregate	3.9
Specific Gravity of Fineaggregate	2.56
Water Absorption Test on Fine Aggregate	1.59%
Bulking of Fine Aggregate	30.73%
Specific Gravity & Water Absorption of Coarseaggregate	2.68 & 1.68%
Specific Gravity of Wollastonite & GGBS	2.97 & 2.85
Size(μm) of Wollastonite & GGBS	< 1 to20 & < 1 to 100
Colour of Wollastonite & GGBS	White & Off-white

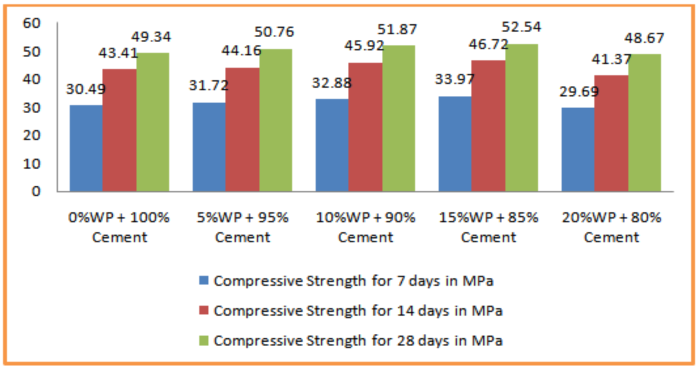
5. MIX DESIGN

Grade	M40
Proportion	1 : 1.70: 3.01
W/C ratio	0.36
Cement	403 Kg/m^3
Fine Aggregate	687 Kg/m^3
Coarse Aggregate	1215 Kg/m^3
Water	145 Kg/m^3
Chemical admixture	4.03 Kg/m^3

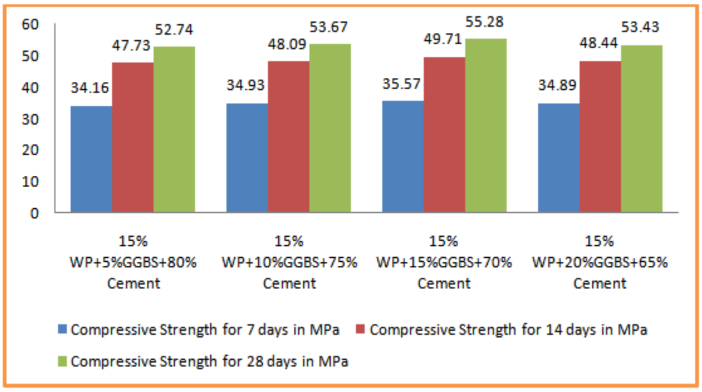
6. PERFORMANCE TESTING & RESULTS

Table No. 6.1 Test results of Compressive Strength for 7, 14 & 28 days for M40

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	30.49	43.41	49.34
5%WP + 95% Cement	31.72	44.16	50.76
10%WP + 90% Cement	32.88	45.92	51.87
15%WP + 85% Cement	33.97	46.72	52.54
20%WP + 80% Cement	29.69	41.37	48.67
15% WP+5%GGBS+80% Cement	34.16	47.73	52.74
15% WP+10%GGBS+75% Cement	34.93	48.09	53.67
15% WP+15%GGBS+70% Cement	35.57	49.71	55.28
15% WP+20%GGBS+65% Cement	34.89	48.44	53.43



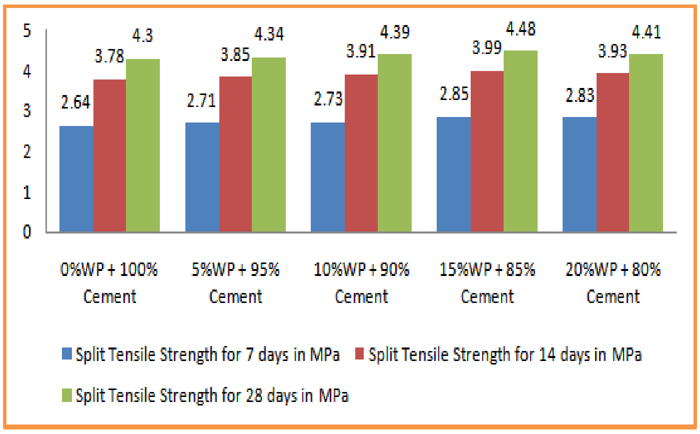
Graph No. 6.1 Development of Compressive strength after curing 7, 14& 28 days for M40



Graph No 6.2 Relation between optimum wollastonite (15%)+%GGBS replacement and Compressive strength

Table no 6.2 Test results of Split Tensile Strength for 7, 14 & 28 days for M40

Mix % Replacement	Split Tensile Strength for 7 days in MPa	Split Tensile Strength for 14 days in MPa	Split Tensile Strength for 28 days in MPa
0%WP + 100% Cement	2.64	3.78	4.30
5%WP + 95% Cement	2.71	3.85	4.34
10%WP + 90% Cement	2.73	3.91	4.39
15%WP + 85% Cement	2.85	3.99	4.48
20%WP + 80% Cement	2.83	3.93	4.41
15% WP+5%GGBS+80% Cement	2.91	4.04	4.52
15% WP+10%GGBS+75% Cement	3.03	4.26	4.75
15% WP+15%GGBS+70% Cement	3.64	4.79	5.14
15% WP+20%GGBS+65% Cement	3.12	4.22	4.61



Graph No 6.3 Development of Split Tensile strength after curing 7, 14 & 28 days for M40

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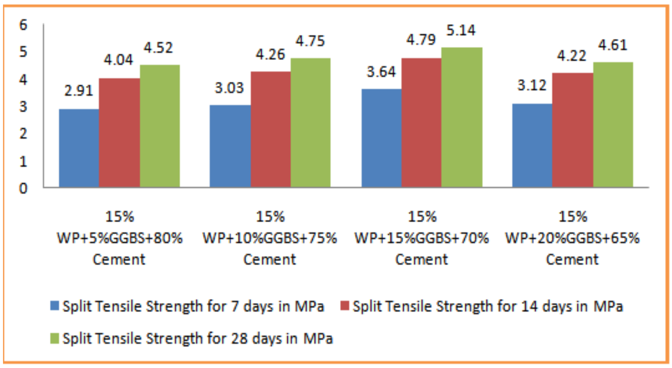
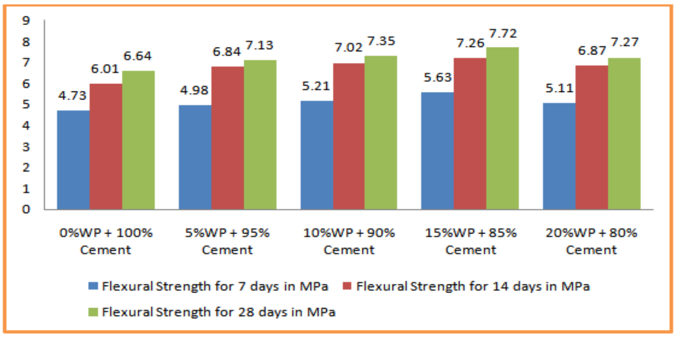


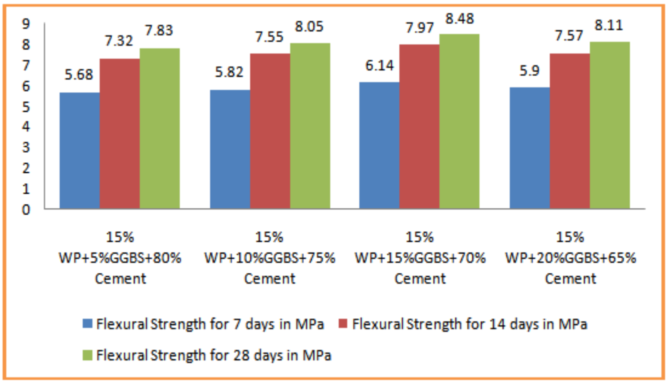
Graph No 6.4 Relation between optimum wollastonite (15%)+%GGBS replacement and Split Tensile strength

Table No 6.3 Test results of Flexural Strength for 7, 14 & 28 days for M40

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	4.73	6.01	6.64
5%WP + 95% Cement	4.98	6.84	7.13
10%WP + 90% Cement	5.21	7.02	7.35
15%WP + 85% Cement	5.63	7.26	7.72
20%WP + 80% Cement	5.11	6.87	7.27
15% WP+5%GGBS+80% Cement	5.68	7.32	7.83
15% WP+10%GGBS+75% Cement	5.82	7.55	8.05
15% WP+15%GGBS+70% Cement	6.14	7.97	8.48
15% WP+20%GGBS+65% Cement	5.90	7.57	8.11



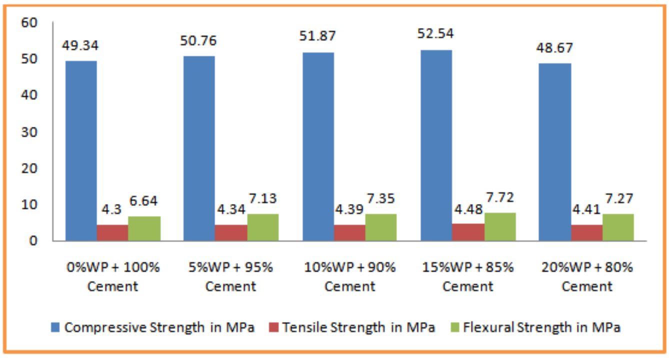
Graph No 6.5 Development of Flexural strength after curing 7, 14 & 28 days for M40



Graph No 6.6 Relation between optimum wollastonite (15%)+%GGBS replacement and Flexural strength

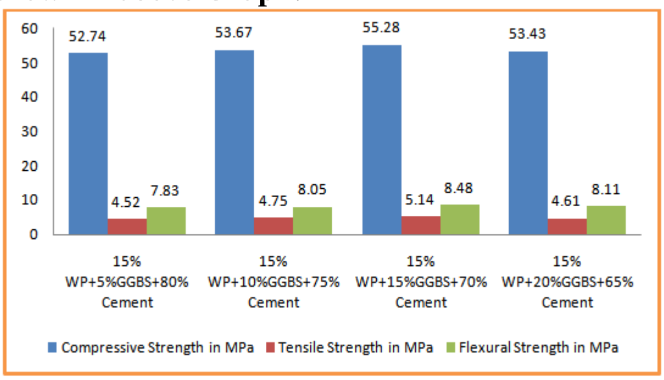
Table no 6.4 Test results of Compressive, Tensile & Flexural Strength for 28 days for M40

Mix % Replacement	Compressive Strength in MPa	Tensile Strength in MPa	Flexural Strength in MPa
0%WP + 100% Cement	49.34	4.30	6.64
5%WP + 95% Cement	50.76	4.34	7.13
10%WP + 90% Cement	51.87	4.39	7.35
15%WP + 85% Cement	52.54	4.48	7.72
20%WP + 80% Cement	48.67	4.41	7.27
15% WP+5%GGBS+80% Cement	52.74	4.52	7.83
15% WP+10%GGBS+75% Cement	53.67	4.75	8.05
15% WP+15%GGBS+70% Cement	55.28	5.14	8.48
15% WP+20%GGBS+65% Cement	53.43	4.61	8.11



Graph No 6.7 Development of Compressive, Tensile & Flexural strength after 28 days for M40

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 52.54 N/mm^2, which is 6.48% higher than the reference mixture where as Tensile strength is 4.48 N/mm^2 which is 4.18% higher than reference mixture and Flexural strength is 7.72 N/mm^2 which is 16.26% higher than reference mixture. The change in strength properties with different proportions of wollastonite replacement cement of class M40 is shown in above **Graph.**



Graph No 6.8 Relation between optimum wollastonite (15%)+%GGBS replacement and Compressive, Tensile & Flexural strength

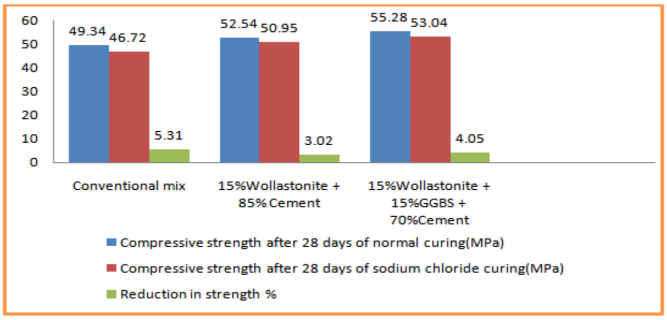
Among all GGBS substitutes, the highest strength is achieved when mixed with grade M40, which contains 15% wollastonite and 15% GGBS. As the GGBS content of concrete increases, its strength properties first increases up to 15% and then decreases. The maximum strength is achieved when the wollastonite content is 15%, and 15% GGBS reaches a compressive strength of 55.28N/mm2 which is 12.03% higher than the composite material where as tensile strength of 5.14N/mm2 which is 19.53% is higher than the composite material and flexural strength of 8.48N/mm2, which is 27.71% higher than the composite materials. The changes in the strength properties of GGBS concrete containing 15% wollastonite and above are shown in above Graph.

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 no 6.4 Test results of Compressive, Tensile & Flexural Strength for 28 days for M40

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	49.34	46.72	5.31
15%Wollastonite + 85% Cement	52.54	50.95	3.02
15%Wollastonite + 15%GGBS + 70% Cement	55.28	53.04	4.05



Graph No 6.9 compressive strength of cubes after Chloride attack

7. 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 6.48%, splitting tensile strength by 4.18% and bending strength by 16.26% 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 12.03%, splitting tensile strength by 19.53% and bending strength by 27.71%.

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

FUTURE OUTLOOK

India is currently the second-largest producer of wollastonite in the world, behind China. The nation's current mines have the capacity to provide both the domestic ceramic industry's needs and the demand from exports. Wollastonite is becoming more and more popular on the global market, particularly in the fields of building, paint, metallurgy, ceramics, and asbestos replacement. The current amount consumed is about 1.5 lac tons. The apparent domestic demand is predicted to increase at a projected growth rate of 9%. To improve the export of value-added products, wollastonite processed with a high aspect ratio and wollastonite powder may be promoted for export. India would be in a strong position to meet future demand if wollastonite deposits were increased in the States of Gujarat and Tamil Nadu..

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. 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
6. "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.
7. "IS 10262-2009, Recommended Guidelines for Concrete Mix Design" Standards, Bureau of Indian Standards, New Delhi, India, 2009.
8. 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.
9. 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)
10. 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