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Original Article

Strength Characteristics of Ternary Blended Concrete with Fly Ash and Wollastonite Mixed in Part to Replace Cement

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Abstract *- Because of the rising demand for concrete around the world, more and more mineral admixtures are being used as whole or partial replacements for cement. These substances can improve the durability of concrete while also drastically lowering the quantity of cement required. This work examines the strength characteristics of ternary blended concrete, with a particular emphasis on the up to 40% substitution of fly ash and Wollastonite. Together with Portland cement, fly ash-an industrial byproduct-and Wollastonite-a naturally occurring mineral with pozzolanic properties-were added as additional cementitious ingredients. The purpose of the study was to evaluate how these replacements might affect the concrete's flexural, split tensile and compressive strengths. In laboratory trials, the percentage of Wollastonite and Fly ash in concrete mixtures was systematically varied up to a maximum replacement level of 40%. The results indicated that the ternary blends had better strength characteristics than standard concrete mixtures. The concrete's ability to enhance its mechanical characteristics by the combination of fly ash and Wollastonite can be determined by its increased flexural, split-tensile, and compressive strengths. Significantly, the study discovered that adding up to 20% more fly ash and Wollastonite to the concrete was an efficient way to achieve the required strength increases without sacrificing the concrete's workability. By using natural minerals and industrial leftovers to lessen the environmental impact of typical concrete manufacturing, this environmentally conscious technique is in line with sustainable construction practices.*

Keywords *- Fly ash, Wollastonite, Workability, Compressive strength, Ternary blended concrete, Pozzolanic.*

1. Introduction

Usually, three ingredients make up concrete: cement, aggregate, and water. After water, concrete is the composite material that is used the most extensively worldwide. Cement, which is the main ingredient in concrete, helps the particles stick together to produce a durable building product. Approximately 1.5 MT of raw materials are needed to manufacture 1 MT of cement. This entity contributes to environmental issues by emitting 0.8 Tons of Carbon Dioxide.

Additional cementitious ingredients are used during the concrete-making process in order to lower the amount of cement used. In recent decades, research has become much more active due to the use of supplemental cementitious materials and the addition of other additives, including admixtures, minerals, and fibres. Metal, mineral, or synthetic fibres can be added to concrete to counteract its tension-related weakness. Nevertheless, the overall cost of the material will go up as a result of this adjustment. Portland cement is frequently replaced with mineral admixtures, including metakaolin, fly ash, and silica fume, to increase the durability and strength of materials. Because of its drastically different compressive and tensile strength characteristics, concrete is a complex material to work with.

The composition of the cement, the properties of the aggregate, and the ratio of cement to water are the main factors influencing the material's resistance. Despite the fact that concrete's compressive strength is frequently highlighted, over the previous 60 to 70 years, a large number of structures have degraded globally. Mainly made for approved uses, blended cement can be found in fly ash-incorporated universal concrete, grouts, mortars and cement-based goods. Later in life, there is an improvement in strength and durability. A combination of Wollastonite and fly ash was used up to 40% in place of cement. A decrease in each strength measure was noted as the wollastonite level increased [1]. Concrete mixes containing fly ash and Wollastonite showed decreased water absorption [2]. Six different concrete mixes-one without any cement substitute-were examined in a different investigation.

Saturated water absorption, rate of water absorption, and coefficient of water absorption were measured when Wollastonite, both with and without microsilica, was used in part instead of cement. It was discovered that adding microsilica (7.5%) and Wollastonite (15%) to concrete significantly increases water tightness by reducing pore space and fine-tuning the microstructure [3]. An increase in wollastonite content was found to result in decreased water absorption and initial surface absorption [4]. The rate of initial surface absorption in concrete mixtures was shown to decrease as the Wollastonite-Fly Ash (W-FA) component increased [1].

Because it primarily controls pore structure improvement, the w/b ratio mainly influences the rate of concrete carbonation [5, 6]. Concrete made with fly ash and slag performs better, which has led to a rise in popularity. Numerous studies have been carried out, and the results show how exposure conditions have a significant effect on durability. Some alterations have been made to this notion based on research conducted in various countries.

The primary subjects of this article are the slump, and compressive strength of an M40 grade Ternary blended concrete, which is composed of cement and cementitious materials like fly ash and Wollastonite. Fly ash is a byproduct of manufacturing that is utilized as a binder. On the other hand, Wollastonite is a mineral that occurs naturally when ground into a fine powder and can be used as a partial substitute for cement.

The addition of different materials to cement improves its workability and pumpability, reduces the likelihood of alkali aggregate reactions, reduces drying shrinkage and creep, strengthens the material's resistance to sulphate attack and chloride penetration, uses less water, and improves bleeding control. The application of Supplementary Cementitious Materials (SCMs) such as fly ash and Wollastonite in ternary blended concrete systems has been thoroughly studied in the field of concrete technology research.

Nonetheless, there is a clear research void in the study of the strength properties of ternary mixed concrete that includes both Wollastonite and fly ash as partial substitutes for cement. Although individual research has examined the impact of fly ash or Wollastonite on the characteristics of concrete, the combined impacts of these two SCMs in a ternary blend remain incompletely known.

The interplay between fly ash and Wollastonite in ternary mixed concrete can produce distinct material behaviours and performance outcomes, which makes this research gap crucial. One area that needs more research is how these SCMs work together to affect mechanical qualities, including flexural strength, tensile strength, compressive strength, and other important ones.

2. Materials Properties and Design Methodology

2.1. Cement

A composite material that functions as a structural binder by drying and chemically bonding to other materials. Ordinary Portland cement, grade 53 certified, serves as the primary binder in controlled concrete. A list of its physical features was determined in Table 1.

2.2. Aggregates

An essential part of concrete, aggregates act as the leading fillers in the mixture. They are essential in defining the general characteristics and functionality of concrete, one of the most extensively used building materials worldwide. Fine and coarse aggregates are the two primary categories of aggregates, each having specific qualities and uses in the concrete mixture. To create concrete with the appropriate qualities, such as strength, workability, and durability, the mix's aggregates must be precisely balanced in terms of quantity, gradation, and quality.

Table 1. OPC grade 53 - physical characteristics

S. No.	Cement Property	Value	Standards as per I.S. 12269:2013
1	Consistency	31%	Not Specified
2	Setting Duration - Initial	45 minutes	Min - 30 min
3	Setting Duration - Final	315 minutes	Max - 600 min
4	Fineness Modulus	343 m^2/kg	225 m^2/kg
5	Soundness	0.6 mm	Not more than 10 mm
6	Specific Gravity	3.15	3.15

Table 2. Characteristics of fine and coarse aggregates

S. No.	Properties	Value
1	Specific Gravity of FA	3.1
2	Water Absorption of FA	2.50%
3	Fineness Modulus of FA	2.3
4	Specific Gravity of CA	2.89
5	Water Absorption of CA	0.4%

Table 3. Chemical properties of wollastonite and fly ash

Compounds	Fly Ash (%)	Wollastonite (%)
Silica (SiO_2)	60	48
Lime (CaO)	4	45
Iron Oxide (Fe_2O_3)	4.00	1.1
Alumina (Al_2O_3)	25.00	4.00
Sulphur Trioxide (SO_3)	0.30	0.20
Magnesia (MgO)	1.00	1.60
Loss of ignition	0.84	0.86

2.3. Water and Admixture

For experimental research, water that complies with IS 456-2000 for building purposes is used. Super plasticizing admixture Supaflow PC350 shows notable acceleration of early-age strength acquisition and notable increase of strength throughout all developmental stages. There are a number of benefits to using precast concrete and other applications that require early solid strength. Additionally, by increasing concrete's ultimate strength and decreasing its permeability, this additive prolongs the material's life. Moreover, it increases the workability of site-mixed and precast concrete without using additional water.

2.4. Adjunct Cementitious Materials

2.4.1. Fly Ash

One essential feature of Class F fly ash is its pozzolanic nature. Pozzolans are materials that generate additional compounds by reacting chemically with calcium hydroxide, which is created during the hydration process of cement.

Fly ash reacts chemically with calcium hydroxide to generate gels of Calcium Aluminate Hydrate (C-A-H) and Calcium Silicate Hydrate (C-S-H). The gels are the substances that give concrete strength and durability. As a result, adding Class F fly ash to concrete mixtures can significantly improve their overall performance.

2.4.2. Wollastonite

A mineral reinforcement called Wollastonite improves the structural integrity of concrete mixtures. Its special qualities, such as its low thermal expansion coefficient and acicular crystal habit, make it a perfect companion for cementitious materials. The cementitious matrix and the needle-like crystals of wollastonite interlace to form a robust, three-dimensional reinforcing network that improves the material's tensile and flexural qualities.

Its ability to resist crack formation and propagation under environmental stress makes it very important. The key to the strength and longevity of concrete is the production of Calcium Silicate Hydrate (C-S-H) gels, which are facilitated by Wollastonite's affinity for calcium hydroxide, a consequence of cement hydration. These gels strengthen the bonds between the component materials, improving the material's overall functionality. Table 3 shows the chemical composition of Wollastonite and fly ash.

2.5. Mix Proportion of Concrete

The composition was created using the guidelines provided in IS 10262-2019 for Conventional Concrete, as reflected in Table 4. At 0.45, the water-to-binder ratio remained uniform during the experiment.

The composition was 60% cement, and the remaining 40% mass was replaced with Wollastonite and fly ash. Table 5 outlines the percentage of mix composition considered for cementitiousand supplementary substances. Table 6 illustrates the mix design formulated for the M40 grade of ternary blendedconcrete in recommended proportions as specified in IS 10262-2019.

Table 4. Mix ratio for M40 grade of concrete

S. No.	Description of Materials	Values of Mix
1	Concrete Grade	M40
2	Concrete Volume (m^3)	1
3	Cement (Kg/m^3)	440
4	Fine Aggregate (Kg/m^3)	624
5	Coarse Aggregate (Kg/m^3)	1166
6	Super Plasticizer (Kg/m^3)	3.52
7	Mix Ratio	1:1.42:2.65
8	Water-Cement Ratio	0.40
9	Water Content (Kg/m^3)	190
10	Slump (mm)	100

Table 5. Composition of cementitious and supplementary substances

Mix ID	Percentage of Composition		
	Cement	Fly Ash	Wollastonite
C.M.	100	0	0
M1	60	40	0
M2	60	30	10
M3	60	20	20
M4	60	10	30
M5	60	0	40

Table 6. Mix design for M40 grade of ternary blended concrete (kg/m^3)

Mix ID	Cement	FA	CA	Fly Ash	Wollastonite	Water	Admixture
C.M.	440	624	1166	0	0	190	3.52
M1	264	624	1166	176	0	190	3.52
M2	264	624	1166	132	44	190	3.52
M3	264	624	1166	88	88	190	3.52
M4	264	624	1166	44	132	190	3.52
M5	264	624	1166	0	176	190	3.52

Table 7. Compressive strength values

Mix ID	Compressive Strength (N/mm^2)			
	3 Days	7 Days	14 Days	28 Days
C.M.	21.48	33.86	48.11	51.23
M1	17.74	26.38	39.42	41.57
M2	20.24	30.37	45.35	48.95
M3	24.12	35.21	51.82	55.35
M4	19.54	29.45	44.67	47.42
M5	18.75	27.42	43.16	45.70

3. Results of the Experiments and Discussions

3.1. Compressive Strength

Concrete's compressive strength is a measurement of how well the material can bear axial loads, or pushing or crushing forces, without breaking. It is among the most significant characteristics of concrete and is frequently used to evaluate the material's overall performance and quality in a range of building applications.

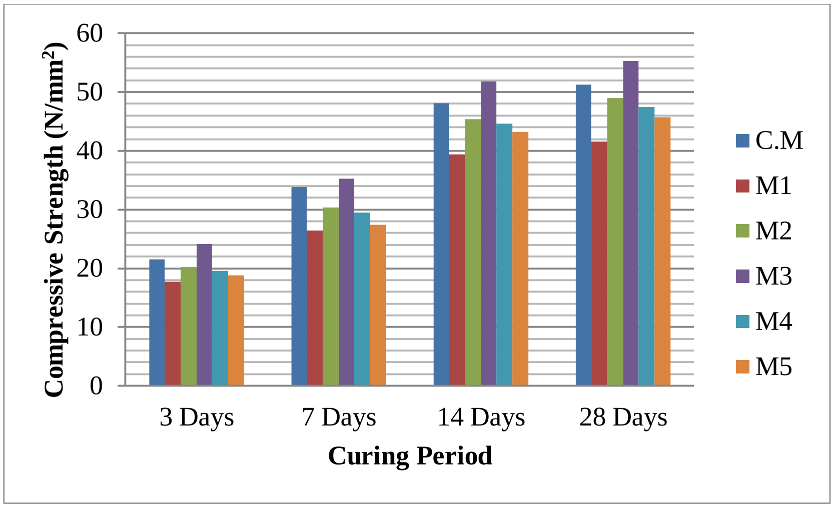

Fig. 1 Compressive strength

The compressive strength values for the specimens cast for specific curing days are displayed in Table 7. Table 7 and Figure 1 made it clear that the third replacement mix (M3) produced a higher compressive strength than the other mixes.

By substituting fly ash and Wollastonite up to 20%, about 4.12 MPa of strength was raised. It is therefore advised to replace 20% of both fly ash and Wollastonite as partial replacement of cement.

3.2. Split Tensile Strength

A particular kind of test is used on a cylindrical or disk-shaped specimen in order to ascertain the split tensile strength of concrete or other materials. In order to break the specimen apart during the test, a force perpendicular to the cylindrical surface must be applied. Although less popular than the typical compressive strength test, this test is nonetheless beneficial for determining how materials would behave when subjected to splitting or tensile stresses in practical applications.

Table 8. Split tensile strength values

Mix ID	Split Tensile Strength (N/mm^2)			
	3 Days	7 Days	14 Days	28 Days
C.M.	2.58	3.79	4.43	5.1
M1	2.47	3.64	4.23	4.9
M2	2.42	3.56	4.3	4.8
M3	2.63	3.86	4.53	5.32
M4	2.37	3.49	4.27	4.7
M5	2.31	3.45	4.23	4.35

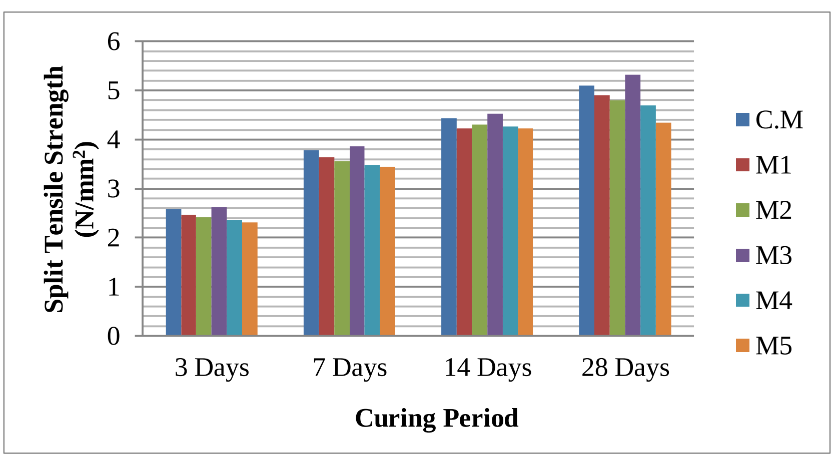

Fig. 2 Split tensile strength

Table 8 shows the tensile strength values of the specimens tested. The results presented in Table 8 and Figure 2 indicate that the third replacement mix (M3) exhibited the highest tensile strength among the tested mixes. By replacing fly ash and Wollastonite with up to 20% substitute, strength was increased by roughly 0.22 MPa while comparing the Conventional Mix (CM). Therefore, it is suggested that 20% of fly ash and Wollastonite be substituted for the cement.

3.3. Flexural Strength

The ability of a material to withstand deformation or failure under bending is measured by its flexural strength, also referred to as its modulus of rupture. Flexural strength is a crucial characteristic of concrete that indicates the material's resistance to applied loads or forces that result in bending. In structural applications, where elements like beams and slabs are subjected to bending loads, it is especially crucial.

Table 9. Flexural strength values

Mix ID	Flexural Strength (N/mm^2)			
	3 Days	7 Days	14 Days	28 Days
C.M.	3.86	5.68	5.92	7.65
M1	3.72	5.46	5.63	7.35
M2	3.64	5.35	5.62	7.2
M3	3.95	6.03	6.15	7.93
M4	3.79	5.57	5.95	7.5
M5	3.56	5.23	5.85	7.05

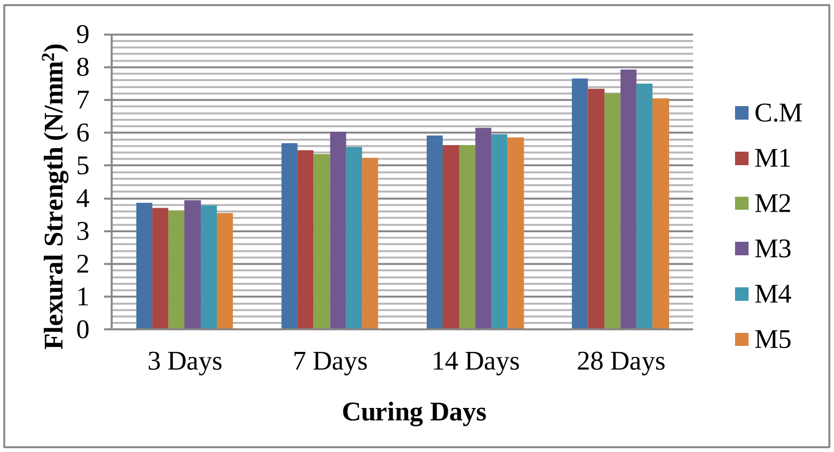

Fig. 3 Flexural strength

Table 9 displays the values of flexural strength over the prismatic specimens. The preceding Figure 3 makes it rather evident that, when compared to conventional and other mixes, the third mix (M3) performed exceptionally well. When compared to the traditional mix, there was an increase of around 0.23 MPa, and all curing days showed improved performance. Therefore, it was advised to replace 20% of the Wollastonite and fly ash in concrete.

4. Conclusion

The investigation into the strength properties of ternary blended concrete, incorporating the replacement of Wollastonite and fly ash up to 20%, has provided valuable insights into the performance of this composite material. The ternary blend, combining ordinary Portland cement with wollastonite and fly ash as supplementary cementitious materials, has demonstrated promising results in enhancing the concrete's strength characteristics. The inclusion of Wollastonite, a natural mineral with pozzolanic properties, and fly ash, a widely used industrial byproduct, has positively influenced the mechanical strength properties of the concrete. The synergistic effect of these supplementary materials has contributed to improved durability and mechanical properties of the concrete mixtures, thereby making them more suitable for structural applications. Notably, the replacement levels of Wollastonite and fly ash up to 20% have proven to be effective in achieving the desired strength enhancements without compromising the overall workability of the concrete.

This environmentally conscious approach, utilizing industrial byproducts and natural minerals, aligns with sustainable construction practices and contributes to the reduction of the carbon footprint associated with traditional concrete production. It is essential to recognize that the success of ternary blended concrete is contingent on careful mix design considerations, including the optimization of proportions and curing conditions. Additionally, the long-term performance and durability of these concrete mixes should be further assessed through extended testing and field applications. In summary, the study on ternary blended concrete with Wollastonite and fly ash replacements up to 20% presents a promising avenue for the development of high-performance, sustainable concrete.

This research contributes to the growing body of knowledge aimed at advancing environmentally friendly construction practices while maintaining or improving the essential mechanical properties of concrete. Future research and real-world applications will continue to refine and validate the potential of ternary blended concrete as a viable and advantageous construction material.

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