

Use of Binary Cementitious Systems Containing Lime Sludge and Wollastonite Powder in Concrete

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Abstract-An important environmental concern is the wide use of cement in the construction industry. In this scenario the cement usage should be reduced using supplementary cementitious materials like Lime-sludge (LS) and Wollastonite-powder (WP). LS and WP, due to their properties and environmental friendliness they have a huge potential as replacements to Ordinary Portland cement (OPC). Using LS and WP as partial replacements in cement long term sustainable cement concrete can be produced. In the current study a novel process is implemented to produce a long-term sustainable concrete using Lime sludge and Wollastonite powder to form binary mixes and validate it by mechanical properties of M30 grade concrete. Cement was partially replaced with mineral admixture lime sludge at 5%, 10%, and 15% by weight of cement to form a binary blended mix and by wollastonite at 10%, 15%, and 20% by weight of cement to form a second binary blended mix. To make a comparison, the strength properties of both the control mix and the blended concrete mixes are determined. The concrete used in this study performed better when mineral admixtures were added. The blended mix concrete had enhanced strength. It was concluded that LS10 and WP15 performed better in terms of strength.

Keywords: Lime-sludge (LS), Wollastonite-powder (WP), Compressive Strength (CS), Flexural Strength (FS), Split Tensile Strength (STS).

1. Introduction

The broad utilization of concrete causes environmental pollution which is inevitable [1]. Cement requirement is increasing day by day with global development and with that there a need to address the critical challenges in cement industry such as CO₂ emission, energy consumption and conservation of materials [2]. One of the major concerns of above listed is CO₂ emissions as production of 1000 kgs of cement approximately releases 1000 kgs of CO₂ into the atmosphere [3]. In addition to CO₂ emissions cement production also releases SO₃ and NO_x, therefore aggravating the acid rain and greenhouse effect [4]. As a result, to address the issues, numerous scientists and researchers were trying to find substitute concrete binders. Blended mixes using Supplementary cementitious materials (SCM's) have benefits in

terms of performance and economy when compared to nominal concrete. The use of SCM's in different combinations reduces pollution problems [5]. To curtail the problems of dumping and pollution coming from these industrial by-products, it is important to use these waste products in a profitable way [6]. Supplementary Cementitious materials sometimes can be referred to as mineral admixtures [7]. They can be used exclusively or in combination in concrete. Many materials like GGBS, silica fume, fly ash, lime sludge, wollastonite is being used as alternative materials [8]. Extensive research is being done on SCM's all over the globe using fly ash, GGBS, SF and many other materials. The new materials like LS; wollastonite and bentonite are rarely investigated as potential partial replacement to cement. In the present investigation the focus is kept on wollastonite and

lime sludge. The paper industry is one of the major sources of Indian economy. There are about 759 mills in India which produces major waste (lime sludge). The dumping of these waste materials is a major concern [9]. So, this waste from paper industry known as lime sludge can be a potential substitute to cement up to a certain extent. Wollastonite is available naturally and the reaction that occurs between silica and limestone in high temperatures results in wollastonite. [10]. It is a calcium-metasilicate (C-S) mineral. It is profusely available in states of Andhra Pradesh, Tamil Nadu, Rajasthan, and Uttarakhand [11]. The production rate of wollastonite per year is about 250,000 MT in the Udaipur mines alone [12]. The utilization of wollastonite powder is determined due to its acicularity or aspect ratio, which is the ratio of a crystal's length to width, chemical characteristics, brightness, and fibre length. Wollastonite offers little potential for reinforcing applications with an aspect ratio of 3:1 to 5:1. [13]. Wollastonite is a C-S mineral that is white in colour and has a needle-like or acicular shape in its natural environment [14]. Because wollastonite is a naturally occurring mineral, it does not need to be synthesized, which contributes to its relatively low cost [15]. Based on its chemical composition which has equal proportions of silica and lime in a favorable size is encouraging to be a potential partial replacement to cement [16]. In the present investigation lime sludge and wollastonite were tried as partial replacement to cement.

2. Objectives And Methodology

The prime objective of the research was to create binary blended mix using supplementary cementitious materials using Lime sludge and wollastonite and to compare with conventional mix in terms of strength. The experimental programme was designed to meet expected objectives. In the present research the optimum dosages of LS and WP that can be partially replaced in cement using IS 10262:2009 guidelines [17]. M30 grade concrete is selected. A Binary blended concrete mix was formed by optimizing LS, by partially replacing cement with 0 to 15% of LS. Later, a second binary blended

concrete mix was formed by optimizing WP, by partially replacing cement with 10 to 20% of WP. These two binary blended mixes are tested for their mechanical properties and compared with control mix. Binary blended concrete was developed using the optimized LS and WP contents. This optimization technique is used to reduce the utilization amount of cement and can also reduce the emission of greenhouse gases in manufacturing of cement [18].

3. Research Significance

Currently, the focus of the construction sector is on substituting cement with locally accessible eco-friendly alternatives. The primary goal is to cut back on the amount of cement that is used in the construction industry, which will in turn lower the amount of greenhouse gases that are released into the atmosphere [19]. In addition, the usage of these SCMs helps to alleviate some of the challenges associated with disposal and landfilling, which are contributing to serious environmental issues. For the sake of ensuring sustainability, it is of the utmost importance to make use of these materials as a profitable alternative to cement. Numerous research concentrated on supplementary cementitious materials, such as FA, metakaolin, SF, GGBS etc., [20] and established that the inclusion of these components resulted in improvement of mechanical and durability properties. A comprehensive literature study revealed that FA and SF are the two most common components utilised to partially substitute cement in blended concrete [21]. Very few have highlighted the use of

LS and WP as one of the additional cementitious components in forming blended mix [22]. Utilizing these two resources is advantageous from an environmental and economic perspective (because two of these components are industrial by products) [18]. Additionally, this provides a solution to the problems of landfills and global warming [23-34]. Considering all the above problems, the current investigation was carried out to check various possibilities.

1) Can LS and WP be utilised in the

preparation of blended concrete mix, or not? How does this substitution impact the strength properties?

4. Literature Review

There has been a growing interest in discovering sustainable solutions for the construction industry in recent years. Researchers have been exploring new supplementary materials in cementitious composites to enhance their properties and promote sustainability. This essay discusses the findings of various studies on the utilization of these materials, highlighting their influence on strength, durability, workability, and environmental impact. These investigations shed light on the potential benefits and challenges associated with incorporating waste and supplementary materials in construction practices. One avenue of research has focused on incorporating waste materials into construction products, addressing waste management challenges while improving material properties. Vieira et al. studied the addition of effluent sludge showcasing the positive impacts on both the construction industry and waste management practices [5]. This approach not only provides a viable alternative to traditional materials but also contributes to waste vaporization. Similarly, Dehwah et al. explored seashell use as a limited replacement for coarse aggregates in concrete, highlighting the potential of seashells as a sustainable alternative, offering insights into waste management and resource conservation [7]. Al-Swaidani et al. investigated the impact of incorporating recycled concrete aggregate-RCA on the strength and durability properties of concrete, demonstrating the potential of RCA as a viable alternative to natural aggregates, contributing to sustainable concrete production [8]. SCM's have been extensively studied for their positive impacts on the properties of concrete. Juenger and Siddique emphasized the importance of incorporating these materials in concrete mixtures to improve strength, durability, and sustainability [4]. Wang et al. provided a review on the utilization of limestone powder as a supplementary cementitious material, discussing its mechanisms, hydration reactions, and microstructural changes in cement [3]. Furthermore,

researchers have explored the utilization of other waste materials as cementitious binders and aggregates. Pacheco-Torgal et al. investigated the potential of waste materials like rice husk ash and sludge ash from sewage as cementitious binders and aggregates, discussing their characterization, properties, and applications in construction materials [10]. Poon et al. conducted a study on the utilization of waste ceramics and construction waste aggregates in concrete, providing insights into the technical feasibility and sustainability aspects of using waste materials as partial replacements for conventional aggregates in concrete production [11]. The addition of supplementary materials has shown promising effects on cementitious composites. Cao et al. did a review on the effects of different sizes of calcium carbonates on cementitious composites, highlighting the influence of particle size on properties such as strength, workability, and durability [1]. Zhang et al. explored the impact of incorporating nano-silica particles on the properties of cementitious materials, emphasizing their potential in improving the performance of cementitious composites, offering opportunities for enhanced construction materials with improved strength and durability [12]. Yücel and Özcan studied the strength and microstructural properties featuring wollastonite synthetic in cement mortar. Their findings revealed the positive influence of synthetic wollastonite on the cement mortars [13]. Jindal et al. conducted a behavioral study on SCC containing wollastonite microfiber as a partial replacement to sand in PQC. The study demonstrated the potential of wollastonite microfiber in improving the performance of SCC, specifically in terms of workability and mechanical properties [14]. Mandrawalia and Gaur investigated the properties of concrete integrating wollastonite microfiber and cutting waste of granite. Their study showed that the addition of wollastonite microfiber and cutting waste of granite improved the strength properties of concrete, offering a sustainable solution for construction materials [15]. Ashraf et al. conducted a multi-scale classification of wollastonite paste and developed schemes to

predict its elastic modulus. The study provided insights into the behavior of wollastonite paste and its potential application in cementitious composites [16]. Zareei et al. conducted a comprehensive experimental study on recycled waste (ceramic) on concrete having wollastonite particles and micro-silica. The investigation highlighted the positive influence [17]. Anjaneya Babu Padavala and Potharaju evaluated the performance of fly ash and silica fume-based concrete in terms of mechanical and durability properties. The study demonstrated the potential of fly ash and silica fume in improving the mechanical strength and durability of concrete, making it a sustainable option for building materials [18]. The addition of supplementary materials has shown significant effects. Annaluru et al. investigated the influence of the grade of parent concrete on RCA made with pozzolanic materials. Their study revealed that the use of pozzolanic materials improved the mechanical properties of recycled aggregate concrete [19]. Xu et al. studied the influence of WP on the hydration and strength properties of magnesium potassium phosphate-based cements. The findings demonstrated that wollastonite enhanced the hydration process and improved the properties of magnesium potassium phosphate cements [20]. Kumar and Prasad conducted a study on the strength and durability characteristics of paper waste-based blended cement concrete. Their research highlighted the positive impact of lime sludge on the strength and durability of blended cement concrete, providing insights into sustainable construction practices. [21]. The utilization of waste and supplementary materials in cementitious composites offers significant potential for sustainable construction practices. Through the incorporation of waste materials, researchers have demonstrated the positive impacts on material properties, waste management practices, and resource conservation [5][7][8]. Additionally, the use of SCM's has shown promising results in enhancing the strength, durability, and sustainability of cementitious composites [3][4][10][11][12]. These studies collectively emphasize the importance of considering alternative materials and approaches to address

environmental concerns in the construction industry. By utilizing waste and supplementary materials, construction professionals can contribute to sustainable development, reduce environmental impacts, and promote the efficient use of resources. Further research and development in this field will continue to expand our understanding and application of these materials, paving the way for a greener and more sustainable future in construction.

5. Methods

5.1 Materials used

5.1.1 Cement

OPC 53 Grade Ultratech cement confirming to IS 12269-1987 [24 25] was used in present investigation. Cement's specific gravity (SG) was 3.12, and its initial setting time (IST) and final setting time (FST) were 45 minutes and 480 minutes, respectively. The physical properties of cement were tabulated in table 5.1.

Table No 5.1: Physical Properties of Cement

S.no	Property	Obtained Value
1	SG	3.12
2	IST	45 min
3	FST	480 min
4	Normal Consistency	32%
5	Fineness Test	5% retained

5.1.2 Fine aggregate (FA)

In the investigation FA of zone 2 confirming to IS 383-1970 was used [26]. The locally available FA was used. The SG was 2.65.

5.1.3 Coarse aggregate (CA)

Crushed and well graded 20mm nominal size confirming to IS: 383-1970 [27] was obtained locally. The SG of coarse aggregate used was 2.81.

5.1.4 Lime Sludge (LS)

LS was obtained from DELTA PAPER MILLS LIMITED, Vendra. The specific gravity was 1.98. The chemical composition of LS was tabulated in 5.2.

Table No 5.2 Chemical Composition of LS

Constituent	Lime Composition (%)	Sludge
CaO	48.37	
SiO ₂	9.42	
Fe ₂ O ₃	2.92	
Al ₂ O ₃	3.18	
MgO	2.45	

5.1.5 Wollastonite Powder

Wollastonite powder is a calcium silicate mineral that is white in colour and has a needle-like or acicular shape in its natural environment [28]. Its chemical composition is CaO-SiO₂ [29-33]. The SG was 2.90. The chemical composition of LS is tabulated in 5.3.

Table No 5.3 Chemical Composition of Wollastonite Powder.

Constituent	Wollastonite Powder (%)
CaO	48.28
SiO ₂	51.62
Fe ₂ O ₃	0.42
Al ₂ O ₃	0.75
MgO	0.05



Figure 1 Curing of Specimens

5.1.6 Water

Potable water was used for curing and mixing as per IS 456-2000.

5.2 Mix Proportion

M30 Grade concrete was used with water cement

ratio of 0.45.

Table 5.4 Mix proportion of M30 Grade concrete

Material	Quantity
Cement	382
FA	680
CA	1132
Water	171.5



Figure 2: Casting of Specimens

5.3 Testing Methods

The CS, STS, and FS of the specimens were evaluated following the guidelines provided by IS 516-2002 and IS 516: 1959 standards, as depicted in Figure 3. The CS testing was done on cubic specimens, while the STS testing was done on cylindrical specimens. The FS testing was done on prismatic specimens. The samples were made according to the standard, put in the testing machine, and loaded in a controlled way. The load was increased until the specimen failed. The failure load was recorded and used to determine the CS, STS, and FS of the specimens.



Figure 3: Testing of Specimens

6. Results and discussions

6.1 Effect of Wollastonite and Lime Sludge on workability in binary blended cement concrete

The workability test evaluates the consistency of concrete. The slump test has a 300 mm height and is shaped like a cone's frustum. The radius of the base is 400 mm, and the top opening is 100 mm. The container is filled with three layers of concrete, each of which is tested for workability. The slump test is achieved in accordance with IS 1199-1959. Cement was partially replaced with mineral admixture lime sludge at 5%, 10%, and 15% by weight of cement to form a binary blended mix and by wollastonite at 10%, 15%, and 20% by weight of cement to form a second binary blended mix and workability of all mixes is shown in figure 4. The addition of LS to the

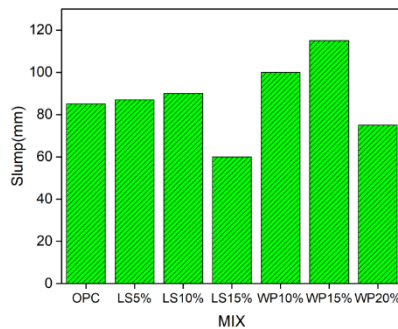


Figure 4: Slump values for binary blended and OPC mixes

cement component improved the workability of binary mixed cement concrete. [30 31]. The fine particle size of LS has enhanced the subsidence of concrete mixture. The workability of LS10 is better when compared with control mix. The slump value for WP mixes increases as WP increases, whereas LS mixes exhibit roughly the same slump as the control mix. Due to dense packing of particles in WP causes increase in slump. As a result, it can be concluded that LS blended mix can retain desired slump when compared with WP blended mix.

6.2 Effect of Wollastonite and Lime Sludge on Compressive Strength (CS) in binary blended cement concrete

The workability test evaluates the consistency of

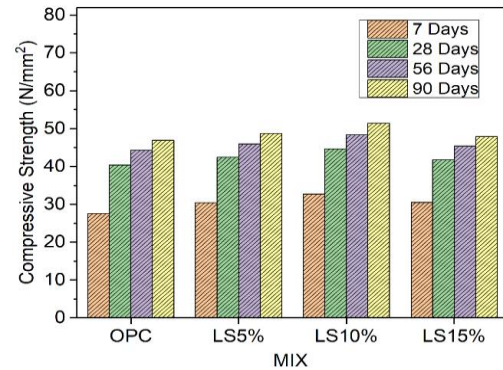


Figure 5: CS for binary blended LS and OPC mixes

concrete. The CS of LS and WP blended mixes at 7, 28, 56 and 90 days were shown in Figure 5 and Figure 6. CS of LS blended concrete is greater than that of the control mix at every age, and CS increases with the addition of LS, with the greatest rise shown at LS10 and a minor decrease observed was at LS15, but LS15 has a higher CS than the control mix. However, the blended concrete containing 5% LS alone reached the target strength by a considerable margin. The calcium content in LS is relatively high. These mineral oxides present in LS when reacted with lime and water, produce calcium silicate gel which is analogous to the chemical compounds produced in cement matrix [19 32]. The particle size of LS is the most important factor in the enhancement of cement's interfacial transition zone. Therefore, at 7, 28, 56 and 90 days, the CS of the LS-containing mixes (LS5, LS10, and LS15) was higher than that of the OPC mix. The optimum content of LS to cement is identified at 10%, as there is little decrease in strength at LS15 when compared to LS10. CS increased up to 15% of cement partial replacement with WP and there is a marginal drop at WP20 when compared with WP15, but WP20 exhibited greater strength when compared to nominal mix. Wollastonite particles were distributed more evenly than cement particles. The wollastonite particles were finer than cement. Therefore, at various ages, the CS of the WP-containing mixes (WP10, WP15, WP20) was higher than that of the OPC mix. The optimum content of WP to cement is identified at 15%, as there is little decrease in strength at WP20 when compared to WP15. The compressive strength of

LS10 and WP 15 are greater when compared to control mix. But when both the blended mixes are compared WP15 performed better when compared to LS10 in terms of CS.

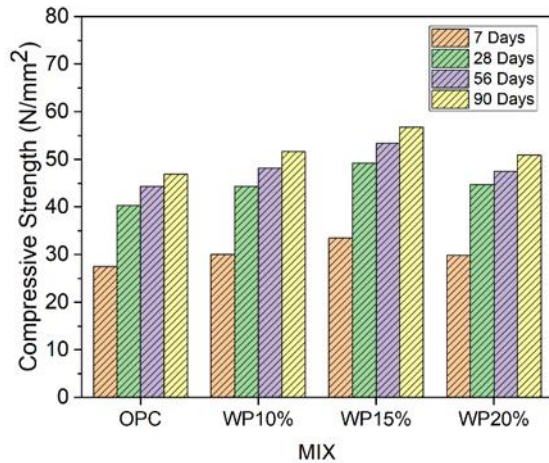


Figure 6: CS for binary blended WP and OPC mixes.

6.3 Effect of Wollastonite and Lime Sludge on Flexural Strength (FS) in binary blended cement concrete

Figure. 7 and 8 displays the Flexural Strength of LS and WP mixes at 7, 28, 56 and 90 days. At 7, 28, 56 and 90 days the FS of LS5, LS10 and LS15 are greater than the control mix because of the LS particles fills the pores of calcium silicate gel and acts as a nucleus to build a strong bond. LS10 exhibits better flexural behaviour when compared with LS15. In case of WP Blended mix WP10, WP15 and WP20 gains greater strength in comparison to nominal mix. The increase in FS is due to the wollastonite particles filling effect, which fills the voids in the mix, and their acicular like shape allows it to connect between a crack's two edges and prevent its additional propagation. A similar trend as in CS is observed in FS variation. The flexural strength of LS10 and WP 15 are greater when compared to nominal mix. But when both the blended mixes are compared WP15 performed better when compared to LS10 in terms of flexural strength.

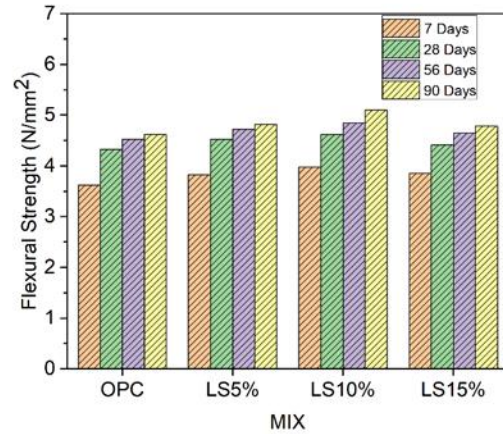


Figure 7: FS for binary blended LS and OPC mixes

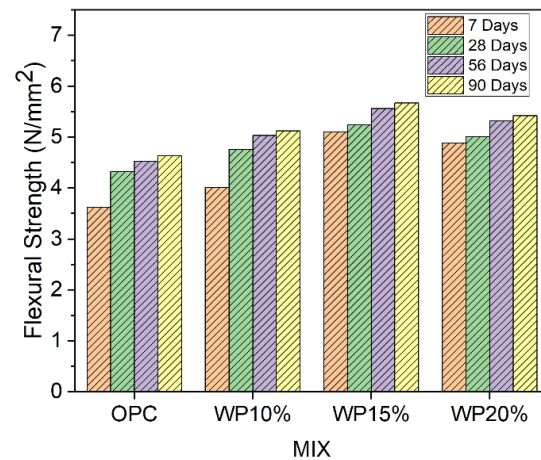


Figure 8: FS for binary blended WP and OPC mixes

7. Conclusions

The study investigated the performance of binary blended mixes LS and WP in terms of strength properties and following conclusions were made:

In economy perspective using WP and LS in cement reduces the overall cost. For this study, the proposed materials such as LS and WP are considered due to their free availability and only the transport cost are incurred.

The workability of LS10 is better when compared with control mix. The slump value for WP mixes increases as WP increases, whereas LS mixes exhibit roughly the same slump as the control mix. Therefore, LS is more preferred material when compared to WP in retaining slump.

- The CS of concrete containing 10% LS increased by 18.75% at 7 days and 10.63% at 28 days when compared to OPC mix. The CS of

concrete containing 10% lime sludge increased by 9.25% at 56 days and 9.64 % at 90 days when compared to control mix.

- The increase in CS of LS-based concrete due to its pozzolanic reaction, nucleation effect, and improved carbonation resistance. Lime sludge contains reactive materials that react with calcium hydroxide, enhancing the hydration process and forming additional cementitious compounds. The fine particles of LS fill the voids in the concrete, leading to denser packing and reduced weaknesses. Lime sludge also acts as a nucleation site, promoting the growth of stronger hydration products. CS has improved as a result of these factors.

- The FS of concrete containing 10% lime sludge increased by 9.94 % at 7 days and 6.94 % at 28 days when compared to OPC mix. The FS of concrete containing 10% lime sludge increased by 7.3 % at 56 days and 10.15 % at 90 days when compared to OPC mix.

- The increase in FS LS-based concrete can be attributed to the pozzolanic activity, improved interparticle bonding, reduced microcracking, and enhanced durability. The reaction of lime sludge with Ca(OH)_2 produces additional cementitious compounds, enhancing the strength of the concrete. The fine particles of lime sludge fill voids, leading to denser packing and stronger interparticle bonding. This reduces microcracking and improves the concrete's ability to withstand bending forces. Additionally, lime sludge-based concrete exhibits improved durability, resulting in enhanced flexural strength over time.

- The optimum content of LS to cement is identified at 10%, as there is little decrease in strength at LS15 when compared to LS10. The CS of the LS-containing mixes (LS5, LS10, and LS15) was higher when compared to OPC mix.

- The CS of concrete containing 15% Wollastonite powder increased by 21.47 % at 7 days and 21.93 % at 28 days when compared to OPC mix. The CS of concrete containing 15% Wollastonite powder increased by 20.7% at 56 days and 21.09 % at 90 days when compared to OPC mix.

- The increase in CS of WP-based concrete due to its reinforcement effect, improved particle

packing, pozzolanic activity, and reduced microcracking. The fine particles of wollastonite improve the packing density of the concrete mixture, resulting in a more compact matrix. Wollastonite's pozzolanic activity leads to the formation of additional cementitious compounds, strengthening the concrete. Additionally, the presence of wollastonite helps reduce the formation and propagation of microcracks, contributing to increased CS.

- The FS of concrete containing 15% WP increased by 40.8% at 7 days and 21.29% at 28 days when compared to OPC mix. The FS of concrete containing 15% WP increased by 23 % at 56 days and 22.46% at 90 days when compared to OPC mix.

- The increase in FS of WP-based concrete can be attributed to its reinforcement effect, improved particle packing, pozzolanic activity, and reduced microcracking. The elongated shape and high aspect ratio enhance the tensile and FS of the concrete. The fine particles of wollastonite improve the packing density of the concrete mixture, resulting in a more compact matrix. Wollastonite's pozzolanic activity leads to the formation of additional cementitious compounds, strengthening the concrete. Additionally, the presence of wollastonite helps reduce the formation and propagation of microcracks, contributing to increased flexural strength.

- The optimum content of WP to cement is identified at 15%, as there is little decrease in strength at WP20 when compared to WP15. The CS and FS of the WP-containing mixes (WP10, WP15, and WP20) were higher than that of the OPC mix. The CS and FS of LS10 and WP 15 are greater when compared to control mix. Therefore, WP is more preferred material when compared to LS in terms of CS and FS.

Further recommendations

To expand on the current research, future studies can explore additional aspects related to the durability of concrete. The incorporation of lime sludge or wollastonite has demonstrated the potential to enhance strength properties. However, it is crucial to investigate the durability of concrete

structures incorporating these materials and understand their effect on the overall life. Moreover, determining the optimal mix proportions for LS and WP is vital. Therefore, further research can focus on identifying the most suitable mixing ratios for different types of concrete applications. While the use of LS and WP as partial replacement can contribute to reducing the CO₂ emissions in concrete production, it is essential to evaluate their overall environmental impact comprehensively. Future studies can undertake a life cycle assessment to environmental implications throughout the entire lifespan of concrete structures. Furthermore, considering the economic feasibility of incorporating LS and WP is crucial. More research is needed to determine whether replacing some of the cement in concrete manufacture can reduce costs. Future research can investigate the economic viability of utilizing these materials in various concrete structures. In summary, future studies can delve into evaluating the long-term durability, environmental impact, and economic feasibility of incorporating LS and WP in concrete. This will contribute to a more comprehensive understanding of their potential benefits and optimal utilization in different construction scenarios.

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