Journal of Information Systems Engineering and Management
2024, 9(4s)
e-ISSN: 2468-4376
https://www.jisem-journal.com/

Research Article

"Mechanical Performance of jute fibre Reinforced concrete with partial replacement of cement by Wollastonic powder"

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ARTICLE INFO

Received: 20 June 2024

Revised: 17 Nov 2024

Accepted: 28 Nov 2024

ABSTRACT

Introduction: Concrete is a commonly employed construction material for a wide range of structures because of its robust structural integrity and strength. Ordinary portland cement is a crucial component in the manufacturing of concrete and is irreplaceable in the civil construction sector. By utilizing industrial by-products as a substitute for cement, sustainable energy and cost savings can be achieved. Wollastonite enhances the functionality of various products, including polymers, plastics, paints and coatings, construction materials, friction devices, ceramics, and more. It has also been utilized in metallurgical applications. Wollastonite powder is utilized in various mixtures that can be substituted for 0% to 18% of cement's weight in concrete, while maintaining a constant percentage of jute fiber. After a curing period of 28 days, the concrete is examined for its compressive strength, flexural strength, and durability. These are in comparison with a standard mixture that contains 0% wollastonite powder and a constant percentage of jute fiber, which determines the optimal combination for replacing the material.

Keywords: Wollastonite Powder, OPC, Concrete, Compressive Strength, Flexural Strength.

INTRODUCTION

Concrete is a commonly employed construction material for a wide range of structures because of its robust structural integrity and strength. The usage, behavior as well as the durability of concrete structure, built during the last first half of the century with ordinary portland cement and plane round bar of mild steel, the ease of procuring the constituents material (whatever may be their qualities) of concrete and the knowledge that almost any combination of the constituents leads to a mass of concrete have bred contempt. The importance of strength was emphasized without considering the durability of the structure. As a consequence of the liberty station, the durability of concrete and concrete structures is on southward journey, a journey that seems to have gained momentum on its path to self-destruction.[20] Ordinary portland cement is a crucial component in the manufacturing of concrete and is irreplaceable in the civil construction sector. Unfortunately, the production of cement releases a significant amount of carbon dioxide gas into the atmosphere, which is a major contributor to the greenhouse effect and global warming. As a result, it is either necessary to find an alternative material or partially substitute it with another material. The search for any material that can be used as a substitute or addition to cement should contribute to global sustainable development and have the least negative impact on the environment. By utilizing industrial by-products as a substitute for cement, sustainable energy and cost savings can be achieved. Fly ash, ground granulated blast furnace slag, rice husk ash, and silica fume are some of the pozzolanic materials that can be used in concrete as a partial substitute for cement. Numerous studies are currently being conducted in India and abroad to examine the effects of using pozzolanic materials as a substitute for cement, and the findings are promising.[22]

Wollastonite is a mineral with incredible characteristics. Until 1970, the primary use of wollastonite was as a decorative stone. Over the past four decades, one of the uses has been as a replacement for asbestos in a wide range of products, such as insulating boards and panels, paint, plastics, roofing tiles, and friction devices like brakes and clutches. Wollastonite is an incredibly versatile filler and reinforcement agent that can be utilized in various

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https://www.jisem-journal.com/
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applications. Wollastonite improves the performance of numerous products, such as polymers, plastics, paints and coatings, construction materials, friction devices, ceramics, and more. It has also been employed in metallurgical applications.[19]

Wollastonite Powder

Wollastonite is a type of mineral that is commonly used in industries due to its chemical composition, which includes calcium, silicon, and oxygen. The molecular formula of wollastonite is CsO3, and its theoretical composition is approximately 48.28% of cao and 51.72% of sio2. Natural wollastonite may contain small amounts or traces of different metal ions, including aluminum, iron, magnesium, potassium, and sodium.[9] Wollastonite is rarely found in its pure form and is often mixed with other minerals such as calcite, garnet, and dropsied, which are considered impurities or gangue minerals that are removed during the extraction process. To achieve the best results, it is important to use the right amount of toning agent in the polymer formulations, ensuring they are properly toned.[13] It has characteristics such as reduced moisture content, low oil absorption, and minimal volatile content. The physical properties of wollastonite are improved by surface modification. It also leads to enhanced processing and improved dispersion if implemented in resin. Wollastonite has numerous applications, including its use in ceramics and paints.[21] (Indian Minerals Yearbook 2020)

Fig 1 Wollastonite Powder

Table 1 Physical properties of Wollastonite Powder [9][13][15]

Property	Details
Color	White to off-white (depending on purity)
Form	Fine powder or acicular (needle-like) crystals
Hardness (Mohs)	4.5 – 5
Density	2.8 – 3.1 g/cm³
Specific Gravity	2.9

Jute Fibre

Jute is a type of fibre that comes from the tiliaceae family. The majority of jute production takes place in countries such as India, Pakistan, China, Bangladesh, and Brazil. Jute fibre has been extensively utilized in the textile, construction, and automotive industries due to its fine texture, low thermal conductivity, and affordability. Similar to other natural fibers, cellulose, hemicellulose, and lignin are the primary constituents of jute fibers. Jute is a long, soft, shiny plant fiber that can be twisted into thick, durable threads. It is derived from the inner bark (also known as bast) of the jute plant, predominantly corchorus olitorius and corchorus capsularis.[1]

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Fig 2 Jute Fibre

Table 2 Physical properties of Jute Fibre [6]

Property	Details
Length	1 to 4 meters (depending on processing and variety)
Diameter	0.02 to 0.2 mm
Color	Natural golden brown to off-white
Lustre	Moderate to high (natural silky sheen)
Density	~1.48 g/cm³

REVIEW OF LITERATURE

Suhad D. Salman et. al. (2020) The use of hybrid composites made from a blend of natural jute and synthetic carbon fibres is becoming increasingly popular across different sectors because of their eco-friendliness and exceptional performance. This study conducted experiments to test the performance of six jute/carbon/pvb composites under compression, tension, and fatigue. The findings indicated that increasing the amount of carbon in the material enhances its resistance to fatigue, while the presence of jute leads to higher levels of strain. Notably, some hybrid stacking sequences (e.g., h1 and h3) exhibited similar fatigue stiffness. Carbon composites exhibited superior resistance to fatigue, while jute composites were more flexible but prone to brittleness. In summary, jute can partially substitute carbon to produce affordable, environmentally friendly composite materials.[1]

Akash Gupta et. al. (2024) This research investigates the process of improving natural fiber composites by combining jute with glass fiber using polyester resin. By utilizing ansys software, 3D models with varying fiber volume fractions were examined to ascertain their impact on effective elastic properties, which closely matched the outcomes of experimental investigations. The composite laminates were subjected to tensile and bending tests for simulation purposes. The hybrid jute + glass fiber/polyester laminate (s2) showed superior mechanical performance, with the highest tensile, bending, and shear strengths outperforming both pure glass (s1) and pure jute (s5) composites. These discoveries emphasize the potential of jute-glass hybrids in creating lightweight, eco-friendly automotive and packaging materials.[2]

Salihu Sarki Ubayi et. al. (2024) This research examines the application of natural jute fibers in strengthening concrete, particularly in the context of sustainable and cost-effective construction in developing nations such as Nigeria. Throughout history, natural fibers have been utilized in traditional construction, showcasing their advantages in minimizing concrete permeability and improving mechanical properties. By reviewing about 40 studies—including experimental work on treated and untreated jute, and admixture-based modifications—the research finds that small amounts of jute fiber significantly improve compressive, tensile, and flexural strength, though higher fiber content reduces workability. The study suggests incorporating superplasticizers and investigating the use of jute-enhanced mortar in future research.[3]

Mahfuza Farzana et. al. (2022) Since the 1990s, natural fiber composites (nfcs), especially those made from jute, have become popular as environmentally friendly and affordable substitutes for synthetic fiber composites in low-

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https://www.jisem-journal.com/
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load applications. Jute possesses exceptional strength-to-weight ratio, low density, excellent thermal conductivity, and is a safer choice for both users and tools. Despite facing obstacles such as inconsistent mechanical properties and limited thermal stability, blending jute with biodegradable polymers results in environmentally friendly "green" composites. Jute possesses exceptional specific strength and stiffness, making it a strong contender for reinforcing biodegradable materials.[4]

Nishant A. Nair et. al. (2021) This research investigates the incorporation of wollastonite as a substitute for cement or sand in concrete to mitigate brittleness and improve tensile strength. Often combined with other materials such as fly ash and silica fume, wollastonite enhances the flexural strength, minimizes shrinkage, abrasion, and water absorption, and enhances durability, particularly against sulfate attack. India, as a leading producer of wollastonite, possesses a substantial supply of this material for various applications. The most favorable outcomes are achieved when wollastonite is combined with recycled waste ceramic aggregates, with a 30% replacement rate resulting in the highest strength and workability levels.[5]

Ishan Anand et. al. (2022) With the rise in construction projects, concrete technology has evolved to include admixtures that enhance performance while also prioritizing environmental sustainability. Fiber-reinforced concrete (frc) offers numerous advantages over plain concrete, including improved tensile strength, stiffness, ductility, crack control, and impact resistance. By incorporating metakaolin as a partial cement substitute, along with jute fibers, the strength of concrete can be enhanced while reducing its environmental footprint. This combination offers a sustainable approach to producing concrete that is both stronger and more durable.[6]

Supriya Xavier Lopes et. al. (2020) This research examines the impact of substituting wollastonite for a portion of cement in m30 grade concrete, with the percentages ranging from 0% to 18%. The mix design was assessed using the standard 10262 (2019) method, and the workability was determined through slump and compaction factor tests. Additionally, the compressive and flexural strengths of the mixes were measured for various combinations. Durability was evaluated by submerging concrete samples in hydrochloric acid (hcl) and magnesium sulfate (mgso4) for 28 days to assess their resistance to chloride and sulfate. The outcomes were analyzed in relation to traditional concrete, emphasizing wollastonite's potential as a sustainable additive that improves both the strength and durability of the material.[7]

P. Raghavendra et. al. (2023) In order to tackle environmental issues in cement manufacturing, this study investigates the substitution of cement with wollastonite and ggbs in m50-grade concrete. Wollastonite, a budget-friendly mineral discovered in Rajasthan, and ggbs aid in reducing carbon dioxide emissions and the depletion of natural resources. Different concrete samples were examined with varying wollastonite contents (5–20%) to determine the ideal level for strength, which was discovered to be 15%. Starting from this foundation, further modifications (5-20%) were made to the ggbs. The highest mechanical performance was attained by using a mixture comprising 15% wollastonite and 15% ggbs, surpassing the capabilities of traditional concrete.[8]

Kiran Kumar M S et. al. (2023) This research investigates the impact of substituting a portion of cement with wollastonite (0–20%) in m30-grade concrete to decrease cement consumption and minimize environmental consequences. Wollastonite, a naturally occurring mineral formed from silica and limestone in magma, is examined for its impact on concrete's mechanical properties. Mix design follows the standard 10262:2019, and its workability is evaluated using slump, compaction factor, and vee-bee tests. The compressive, split tensile, and flexural strengths of each mix are assessed and compared to standard concrete, highlighting wollastonite's potential as a sustainable alternative.

Summary and Gap Identification

The analysis of previous research indicates a rising fascination with incorporating natural fibers and mineral-based substitutes in concrete technology to improve strength and minimize ecological footprint. Researchers have examined natural fibers like jute to determine their potential in enhancing the tensile strength, minimizing cracking, and improving post-cracking ductility in concrete composites. Their eco-friendliness, affordability, and widespread availability in developing regions make them an appealing substitute for synthetic fibers. Although individual studies have been conducted on jute fibres and wollastonite powder, there is a scarcity of research that examines their combined impact on the mechanical properties of concrete. Most studies have primarily examined

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2024, 9(4s)
e-ISSN: 2468-4376
https://www.jisem-journal.com/
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the replacement levels of wollastonite up to 10–12%. The impact of increasing replacement levels (13%, 16%, and 18%) in conjunction with constant jute fibre has not been extensively investigated.

Objectives

1. To examine the strength characteristics of the wollastonite powder and jute fiber mixed specimens and to compare them with conventional specimens.
2. To study the behavior of beams with varying percentages of wollastonite as cement, ranging from 0% to 18%, and jute fiber with a constant percentage of 1%. The compressive and flexural strength properties have been examined for each mix.

METHODOLOGY

1) Data Collection:

Gather pertinent information from scholarly sources and previous research concerning the utilization of wollastonite and its impact on concrete.

Collect information on the material characteristics, such as cement, wollastonite powder, aggregates, and fibers, as well as the mix design, curing techniques, and test outcomes from previous studies.

2) Material Used:

- **Cement:** ordinary portland cement (opc) of standard grade (e.g., 53-grade cement) will be used as the base material.
- **Wollastonite Powder:** A naturally occurring mineral used as a partial replacement for cement The wollastonite powder will be obtained regionally.
- **Coarse Aggregate:** crushed stone aggregates with a size range from 10 mm to 20 mm.
- **Fine Aggregate:** natural river sand with a specific fineness modulus (e.g., 2.5-3.0).
- **Jute Fibre:** natural fibers added to the concrete mix to enhance mechanical properties, used at constant proportion 1%.
- **Water:** Clean, potable water, free from impurities, to ensure proper hydration of cement and to maintain workability of the mix.

3) Mix Design:

- **Grade of Concrete:** The M30 grade concrete mix will be designed using IS 10262:2019.
- **Replacement Proportions:** Cement will be partially replaced with wollastonite powder at different percentages (e.g., 0%, 10%, 13%, 16%, and 18%).
- **Jute Fibre Addition:** Jute fibers will be added at constant proportions (e.g., 1%) to observe their effect on the mechanical properties of the concrete.
- **Water-Cement Ratio:** The water-cement ratio will be adjusted according to the mix design guidelines to maintain adequate workability and strength development.

Table 3. Mix Proportion for casting Cube

Wollastonite Powder %	Cement (kg)	Wollastonite Powder (kg)	Jute Fiber %	Jute Fiber (Kg)	Sand (kg)	Aggregates (kg)	Water lit
0%	2.27	0	0	0	3.91	5.74	1.02
10%	2.04	0.23	1%	0.22	3.91	5.74	1.02
13%	1.97	0.30	1%	0.22	3.91	5.74	1.02
16%	1.91	0.36	1%	0.22	3.91	5.74	1.02
18%	1.86	0.41	1%	0.22	3.91	5.74	1.02

Table 4. Mix Proportion for casting Beam

Wollastonite Powder %	Cement (Kg)	Wollastonite Powder (Kg)	Jute Fiber %	Jute Fiber (Kg)	Sand (Kg)	Aggregates (Kg)	Water
0%	10.57	0	0	0	17.78	26.74	4.75
10%	9.51	1.06	1%	0.105	17.78	26.74	4.75

Journal of Information Systems Engineering and Management
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e-ISSN: 2468-4376
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13%	9.20	1.37	1%	0.105	17.78	26.74	4.75
16%	8.88	1.69	1%	0.105	17.78	26.74	4.75
18%	8.67	1.90	1%	0.105	17.78	26.74	4.75

4) Casting Specimen:

- **Cube Specimens:** Concrete cubes of size 150 mm x 150 mm x 150 mm will be cast for testing compressive strength.
- **Beam Specimens:** Beam specimens of size 150 mm x 150 mm x 700 mm will be cast to evaluate flexural strength.

All specimens will be prepared according to the mix design and the addition of wollastonite and jute fiber, and then properly labeled for identification.

5) Curing:

After the casting process, all specimens will be removed from the mold after 24 hours and undergo water curing for 7, 14, and 28 days. The curing process will take place in a standard curing tank, where the specimens will be immersed in clean water to guarantee proper hydration and the growth of strength.

6) Testing of Specimens:

- **Workability:** The workability of each mix will be determined using the slump test, compaction factor test, and vee-bee consistometer to evaluate the ease of handling and compaction of the concrete mix.
- **Compressive Strength:** Compressive strength will be tested by applying a gradually increasing load on the 150 mm cubes at 7, 14, and 28 days of curing The highest amount of weight the material can withstand before breaking will be measured, and the strength of the material will be determined.
- **Flexural Strength:** Flexural strength will be determined using a three-point bending test on the beam specimens the beam will be loaded at its midpoint until it breaks, and the flexural strength will be determined using standard formulas.
- **Durability:** Durability tests, including chloride resistance and sulfate resistance, will be conducted by immersing the concrete cubes in mgso4 (magnesium sulfate) solutions for 28 days The alterations in strength will be documented to evaluate the concrete's ability to withstand chemical assault.

RESULTS AND DISCUSSION

Results for Wollastonic Powder.

Compressive Strength for Wollastonic powder

Table 5 Compressive Strength (Wollastonic powder)

Compressive Strength (Wollastonic powder)										
%	**0%**		**10%**		**13%**		**16%**		**18%**	
	Load	Strain	Load	Strain	Load	Strain	Load	Strain	Load	Strain
7 Days	406.2	18.05	448.1	19.92	478.2	21.253	532.3	23.66	453.9	20.17
	412.9	18.35	441.4	19.62	451.6	20.071	551.1	24.49	458.7	20.39
	409.5	18.20	448.7	19.94	465.2	20.676	548.2	24.36	448.2	19.92
14 Days	582.9	25.907	598.9	26.62	652.9	29.018	693.7	30.83	614.7	27.32
	578.1	25.693	607.5	27.00	641.9	28.53	696.1	30.94	625.3	27.79
	602.8	26.791	603.2	26.81	650.4	28.907	691.9	30.75	631.0	28.044
28 days	698.2	31.031	720.1	32.00	778.6	34.60	832.4	37.00	751.9	33.42
	679.4	30.196	709.4	31.53	798.4	35.484	828.3	36.81	721.4	32.062
	701.8	31.191	716.0	31.82	790.7	35.142	829.1	36.85	738.1	32.804

Journal of Information Systems Engineering and Management
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e-ISSN: 2468-4376
https://www.jisem-journal.com/

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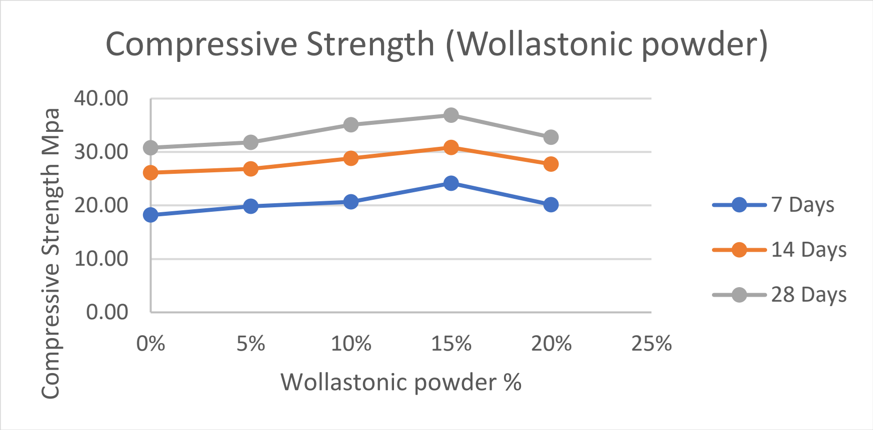


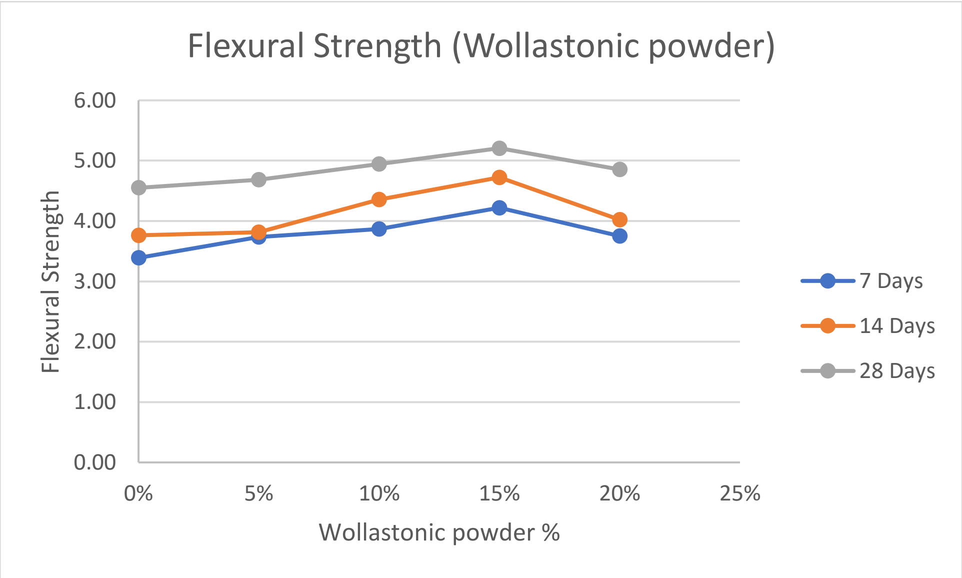
Graph 1 Compressive Strength (Wollastonic powder)

Above Results show that there is a marginal increase in Compressive strength in replacement of Wollastonic powder up to 16% at the age of 7, 14, 28 days and gets slightly decreased at the 18%.

Flexural Strength for Wollastonic Powder.

Table 6 Flexural Strength (Wollastonic powder)

Flexural Strength (Wollastonic powder)					
%	**0%**	**10%**	**13%**	**16%**	**18%**
7 Days	3.31	3.71	3.86	4.23	3.75
	3.47	3.72	3.89	4.18	3.79
	3.39	3.78	3.86	4.25	3.71
14 Days	3.75	3.81	4.25	4.71	4.01
	3.73	3.83	4.44	4.78	3.99
	3.81	3.8	4.37	4.68	4.07
28 days	4.55	4.71	4.98	5.2	4.83
	4.51	4.69	4.91	5.18	4.86
	4.59	4.66	4.95	5.24	4.88



Graph 2 Flexural Strength (Wollastonic powder)

Above Results show that there is a marginal increase in Flexural Strength in replacement of Wollastonic powder up to 16% at the age of 7, 14, 28 days and gets slightly decreased at the 18%.

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2024, 9(4s)
e-ISSN: 2468-4376
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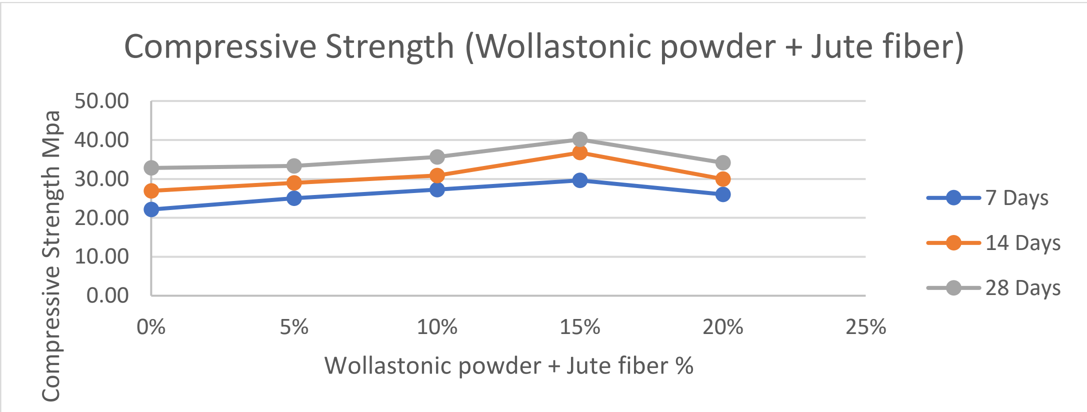
Results For Wollastonic Powder + Jute Fiber

Compressive Strength for Wollastonic powder + Jute fiber

Table 7 Compressive Strength (Wollastonic powder + Jute fiber)

Compressive Strength (Wollastonic powder + Jute fiber)										
%	0%		10%		13%		16%		18%	
	Load	Strain	Load	Strain	Load	Strain	Load	Strain	Load	Strain
7 Days	492.80	21.90	563.60	25.05	601.20	26.72	663.20	29.48	597.40	26.55
	503.40	22.37	569.00	25.29	625.40	27.80	687.10	30.54	586.50	26.07
	498.50	22.16	558.10	24.80	613.70	27.28	648.90	28.84	572.90	25.46
14 Days	597.70	26.56	654.20	29.08	689.60	30.65	823.50	36.60	677.10	30.09
	612.20	27.21	643.10	28.58	694.40	30.86	832.40	37.00	665.70	29.59
	608.40	27.04	660.80	29.37	701.10	31.16	824.10	36.63	678.40	30.15
28 days	732.30	32.55	746.50	33.18	798.80	35.50	899.20	39.96	768.10	34.14
	749.30	33.30	750.60	33.36	793.10	35.25	905.10	40.23	775.20	34.45
	732.90	32.57	750.10	33.34	814.60	36.20	903.70	40.16	761.70	33.85



Graph 3 Compressive Strength (Wollastonic powder + Jute fiber)

Above Results show that there is a marginal increase in Compressive strength in replacement of Wollastonic powder + Jute fiber up to 16% at the age of 7, 14, 28 days and gets slightly decreased at the 18%.

Flexural Strength for Wollastonic powder + Jute fiber

Table 8 Flexural Strength (Wollastonic powder + Jute fiber)

Flexural Strength (Wollastonic powder + Jute fiber)					
%	0%	10%	13%	16%	18%
7 Days	2.47	2.58	2.68	2.97	2.66
	2.36	2.68	2.71	2.95	2.71
	2.38	2.41	2.68	2.99	2.69
14 Days	3.07	3.61	3.81	4.01	3.81
	3.09	3.58	3.79	3.97	3.77
	3.01	3.52	3.83	3.99	3.77
28 days	3.99	4.06	4.35	4.48	4.34
	4.01	4.03	4.28	4.51	4.38
	3.94	4.11	4.32	4.56	4.36

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https://www.jisem-journal.com/

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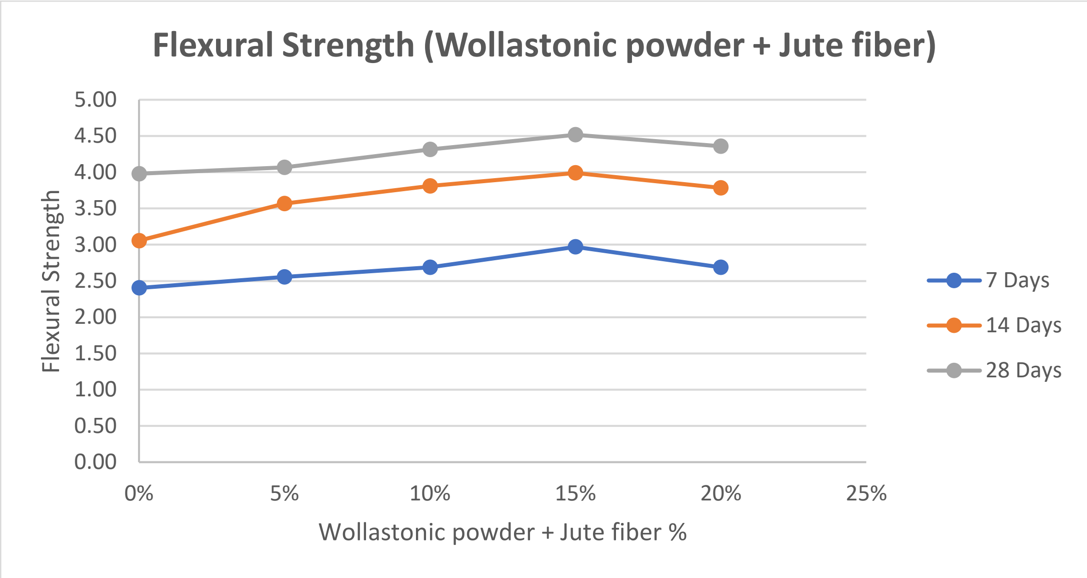


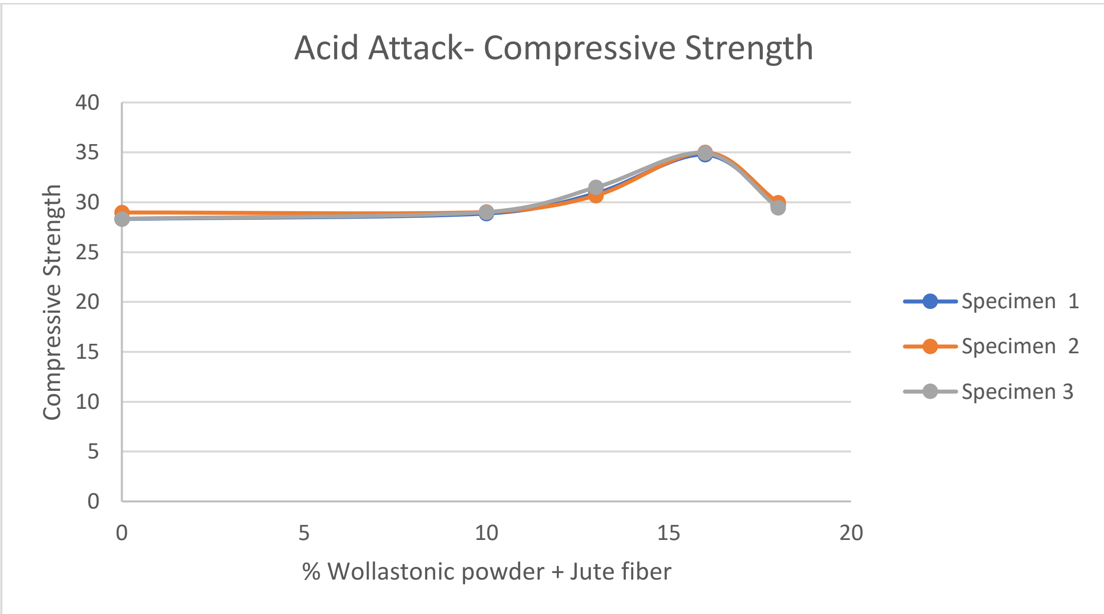
Graph 4 Flexural Strength (Wollastonic powder + Jute fiber)

Above Results show that there is a marginal increase in Flexural Strength in replacement of Wollastonic powder + Jute fiber up to 15% at the age of 7, 14, 28 days and gets slightly decreased at the 20%

Durability Test for Wollastonic powder + Jute fiber

Table 9 Compressive Strength for 28 Days- after Acid attack test

Compressive Strength (Wollastonic powder + Jute fiber)			
Percentage	Specimen 1	Specimen 2	Specimen 3
0%	28.32	28.97	28.34
10%	28.87	29.02	29.01
13%	30.89	30.67	31.49
16%	34.77	35	34.94
18%	29.7	29.97	29.45



Graph 5 Compressive Strength for 28 Days- after Acid attack test

Journal of Information Systems Engineering and Management
2024, 9(4s)
e-ISSN: 2468-4376
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Above Results show that there is a marginal decrease in Compressive strength after acid attack test on specimen of replacement of Wollastonic powder + Jute fiber. jute fibre can affect the performance of concrete in acid attack tests, Jute is less resistant to acids compared to other properties like heat and fire resistance

CONCLUSION

A detailed study has been carried out on the Compressive and tensile strength of concrete with varying the various percentage of Wollastonic powder and jute fiber. Experimental investigation was carried out to check suitability and veracity of the Plain concrete mix with Wollastonic powder for 10, 13, 16, 18% with cement and jute fiber for constant percentage on performance of concrete. Inclusion of Wollastonic powder for cement performs better up to 16%, and similarly, inclusion of Wollastonic powder with jute fiber also performs better up to 16%, adding both together gives excellent performance results of replacement. Hence the following conclusion is considered based on the results and observations are following.

- There is a marginal increase in Compressive strength in replacement of Wollastonic powder up to 16% at the age of 7, 14, 28 days and gets slightly decreased at the 18%.
- There is a marginal increase in Flexural Strength in replacement of Wollastonic powder up to 16% at the age of 7, 14, 28 days and gets slightly decreased at the 18%.
- There is a marginal increase in Compressive strength in replacement of Wollastonic powder + Jute fiber up to 16% at the age of 7, 14, 28 days and gets slightly decreased at the 18%.
- That there is a marginal increase in Flexural Strength in replacement of Wollastonic powder + Jute fiber up to 16% at the age of 7, 14, 28 days and gets slightly decreased at the 18%
- There is a marginal decrease in Compressive strength after acid attack test on specimen of replacement of Wollastonic powder + Jute fiber. jute fibre can affect the performance of concrete in acid attack tests, Jute is less resistant to acids compared to other properties like heat and fire resistance.

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