



Investigation on Sisal Fibre Concrete with Waste Foundry Sand as Partial Replacement of Fine Aggregate

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Abstract: The growing demand for sustainable building materials has led to exploring ecological alternatives to traditional concrete components. This study studies the mechanical properties and sustainability of reinforced concrete of sisal fibers incorporating waste foundry sand (WFS) in partial replacement of fine aggregates. Known for its natural strength, Sisal fibers increase the elasticity and flexible properties of concrete, while WFS from the metal industry provides an effective solution for waste disposal and resource preservation. In this study, class M30 concrete was prepared with different proportions of WFS (10%, 20%, 30%, 40%), replacing the fine aggregates and 1 % by volume of cement sisal fibers are added. Experimental tests were conducted to assess compression resistance, flexural strength, and tension resistance. The results show that inclusion of WFS improves the properties of concrete resistance to optimal exchange levels, while sisal fibers increase crack resistance and the ability to absorb energy. In addition to 20% of WFS replacements, there is a decline in productivity due to poor performance and increased vacuum content. This study concludes that the combination of Sisal and WFS offers a promising alternative for sustainable concrete production, contributing to environmental preservation and reducing construction costs.

Keywords: Waste Foundry Sand, Sisal Fiber, Compressive Strength, Flexural Strength

1. Introduction

Concrete is the most used building material of its universality, resistance and durability. Nevertheless, the general use of natural resources for specific production arouses concern concerning the stability of the environment. In recent years, researchers have studied alternative materials to reduce environmental impact and improve specific characteristics. One of these approaches is the inclusion of industrial waste and natural fibers in concrete. This study focuses on the combined effect of Sisal Fiber and Waste Foundry Sand (WFS) [1,2] in concrete. Sisal fiber, natural fiber obtained from the leaves of the plant of *Agave Sisalana*, is

known for its excellent strength, flexibility and environmentally friendly characteristics. Adding sisal fibre enhances concrete's crack resistance, impact strength, and energy absorption capacity.

On the other hand, WFS is a by-product generated in metal casting industries, often discarded as waste. The use of WFS in partial replacement of fine aggregation not only solves the problem of waste elimination but also retains natural sand resources. WFS is rich in silica content and can improve the mechanical properties of concrete when used in appropriate proportions. In this study, we examine the effects of various WFS substitution levels (10%, 20%, 30%, 40%) combined with the fixation rate (1% volume) of SISAL fibers [3,4] on mechanism properties and sustainability of class M30[5,6]. The purpose of this study is to assess the optimal proportion of mixtures that balance strength, sustainability and environmental stability. The results of this study should provide an overview of sustainable construction practices by encouraging effective use of waste while improving concrete performance.

2. Basic Material Test

Various tests have been conducted on the materials used in the concrete. The test results are furnished in Table 1 to Table 4.

Table 1. Basic Test results of the Cement grade – OPC 53

Sl.No	Properties	Test Results
1	Normal consistency	0.30
2	Consistency	32%
3	Initial setting time	34min
4	Final setting time	600min
5	Specific gravity	3.15
6	Fineness	95%

Table 2. Basic Test results of the 20 mm Coarse aggregate

S.No	Description	Test Results
1	Nominal size used	20mm
2	Specific gravity	2.68

3	Impact value	10.6%
4	Water absorption	0.45%
5	Agg crushing value	20.19%

Table 3. Basic Test results of the Fine aggregate

S.No	Description	Test Results
1	Fines modulus	3.95%
2	Specific gravity	2.56
3	Water absorption	2.24%

Table 4. Basic Test results of the Waste Foundry sand [5,6]

S.No	Description	Test Results
1	Specific gravity	2.45
2	Water absorption	1.42%

3. Mix Proportion

Final mix proportions for M30 grade concrete

C	:	FA	:	CA	:	water
406	:	652	:	1113	:	203
1	:	1.6	:	2.7	:	0.50

4. Fresh Concrete Test

Slump Test

Slump Cone tests are a key assessment of consistency, cohesion and ease of treatment of fresh concrete. Its value is to ensure that the concrete mixture meets the required performance standards for construction. Table 5 furnishes the test results of the workability test with different percentage replacement of waste foundry sand. Figure 1 shows the graphical representation of the workability test of the M30 grade concrete [7,8].

Table 5. Slump Test Result		
Mix design	Fine aggregate replacement by waste foundry sand	Workability
M1	0%	85mm
M2	10%	78mm
M3	20%	80mm
M4	30%	65mm
M5	40%	61mm

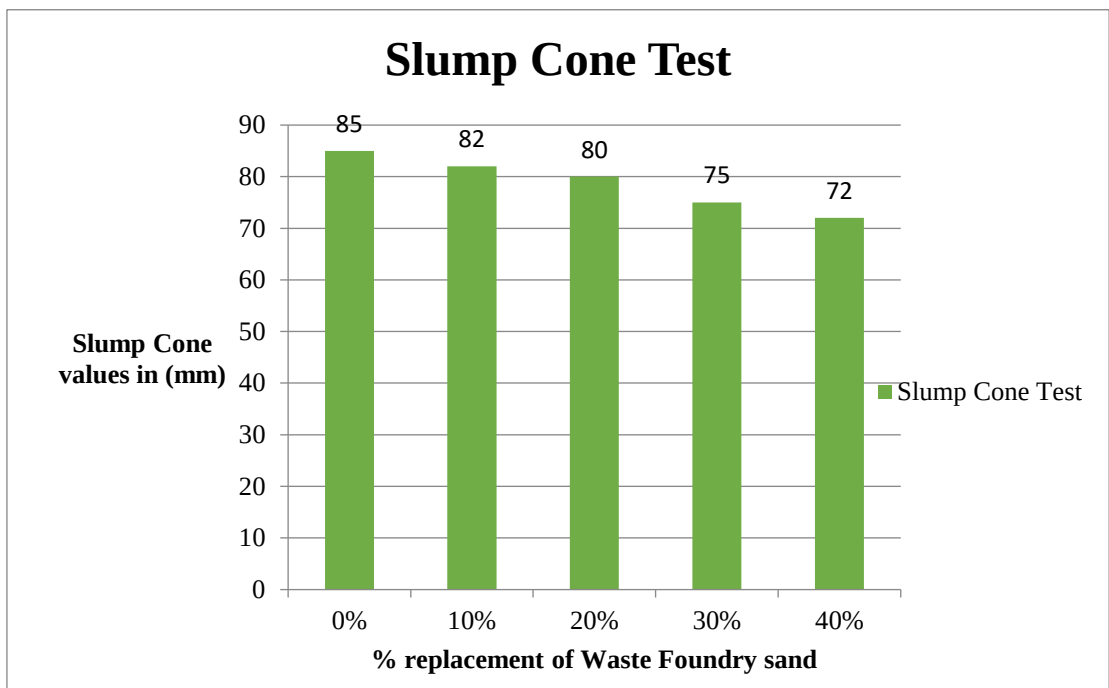


Figure 1. Graphical representation of the workability test result of the M30 grade concrete

5. Results and Discussions

The mechanical properties of concrete are important to ensure the structural integrity, safety and sustainability of concrete structures. Properties such as compression strength, tensile strength and flexural resistance determine the ability of concrete to resist various charges and constraints in real applications. The hardened concrete

test results are furnished in Table 6 to Table 8. The graphical representation of the test results is shown in Figure2, Figure 3 and Figure 4.

Table 6. Compressive Strength Test Result For Cube

Mix design	% of waste foundry sand replaced	Test results for M30 in N/mm ²		
		7 days	14days	28 days
M1	0%	25.2	31	38.5
M2	10%	26.5	33.7	41.3
M3	20%	27.6	35.5	43.2
M4	30%	24.3	31.3	39
M5	40%	23.6	28.2	36.7

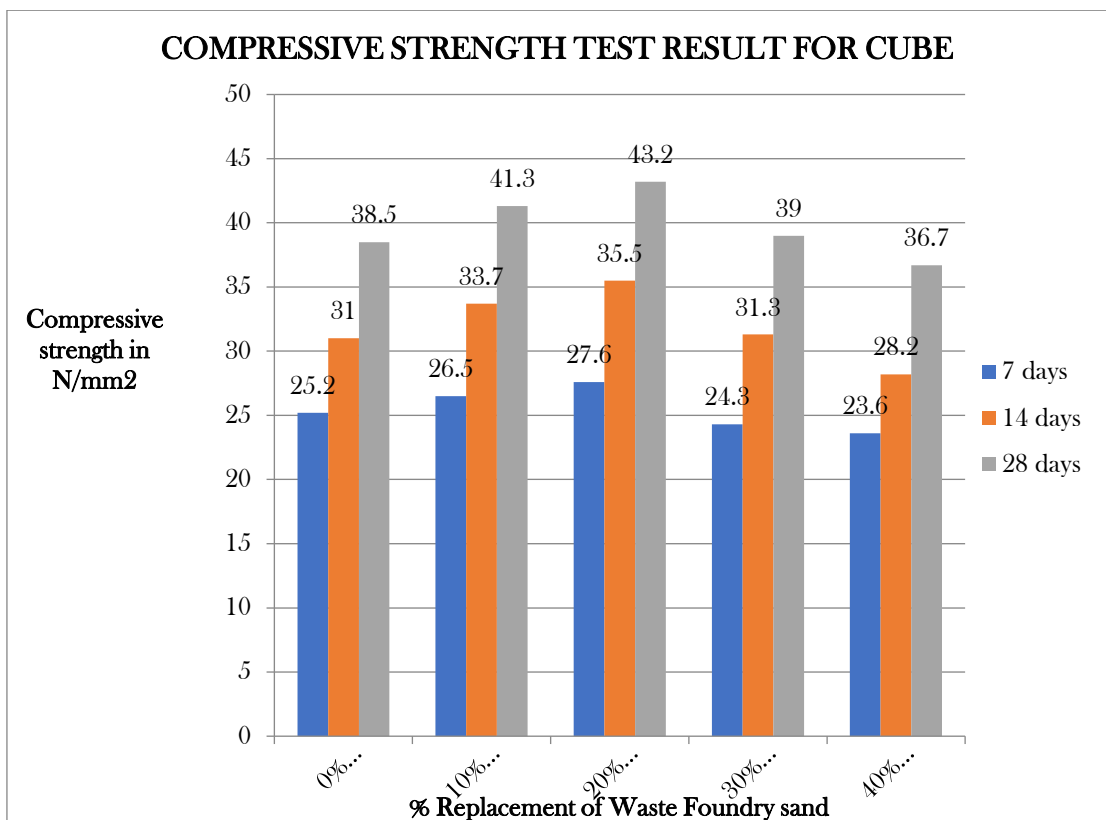


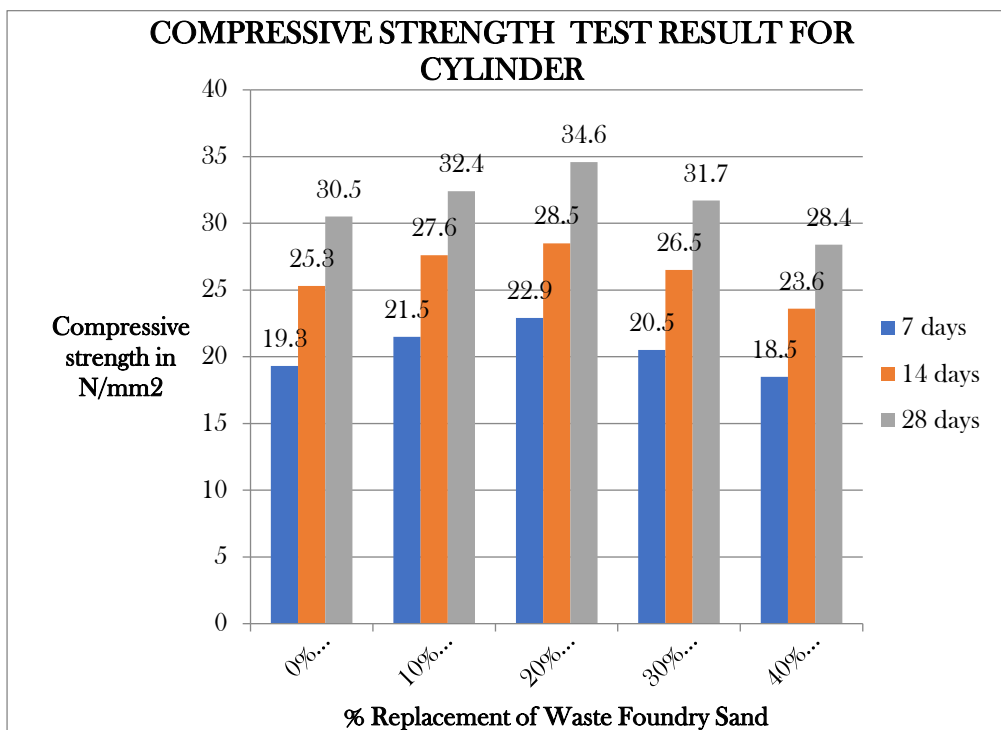
Figure 2. Graphical Representation of Compressive Strength Test Result for Cube

Observations:

From the compressive strength test, it has been found that when fine aggregate is replaced with 20% waste foundry sand, there is great improvement in the compressive strength of the concrete. But when the percentage of replacement is increased it has been found that the compressive strength tends to decrease.

Table 7. Compressive Strength Test Result For Cylinder

Mix design	% of waste foundry sand replaced	Test results for M30 in N/mm ²		
		7 days	14days	28 days
M1	0%	19.3	25.3	30.5
M2	10%	21.5	27.6	32.4
M3	20%	22.9	28.5	34.6
M4	30%	20.5	26.5	31.7
M5	40%	18.5	23.6	28.4

**Figure 3. Graphical Representation of Compressive Strength Test Result for Cylinder**

Observation

The highest performance is often achieved by replacing 20% of the fine aggregate with WFS, which improves particle packing and increases strength. Decreased Trend with Higher Replacement Levels: Beyond 30% WFS, compressive strength decreases due to high fines content in the cementitious matrix.

Spilt Tensile Streth Test

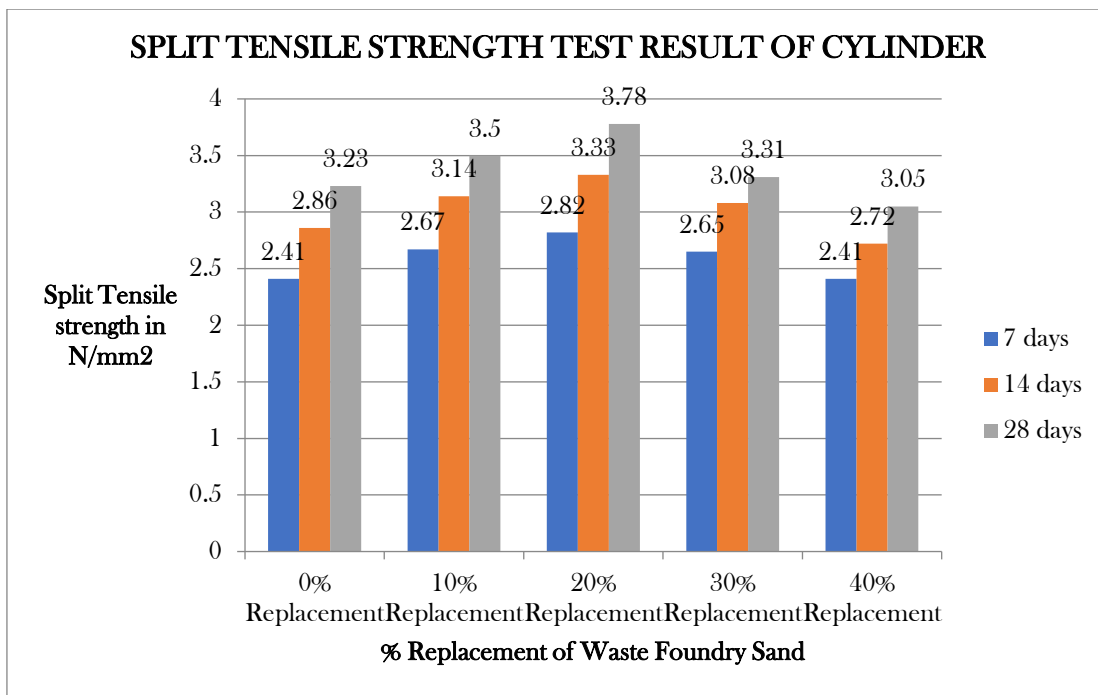


Figure 4. Graphical Representation of Spilt Tensile Strength Test Result

Table 8. Spilt Tensile Streth Test Result

Mix design	% of waste foundry sand replaced	Spilt tensile strength of M30 grade in N/mm ²		
		7 days	14 days	28 days
M1	0%	2.41	2.86	3.23
M2	10%	2.67	3.14	3.5
M3	20%	2.82	3.33	3.78
M4	30%	2.65	3.08	3.31
M5	40%	2.41	2.72	3.05

Discussions

Compressive Strength Test of Cube & Cylinder Specimens

1. At 10% WFS + 1% SISAL FIBRE

- The fine nature of WFS contributes to better strength development through improved particle packing and bonding.
- Sisal fibre improves crack resistance while marginally increasing compressive strength.

2. At 20% WFS + 1% SISAL FIBRE

- This is often the peak performance phase where the concrete matrix obtains higher density, better bonding, and increased strength qualities.
- The combination of WFS's filler effect and sisal fibre's crack-bridging action results in a well-balanced mix with better load resistance.

3. At 30% WFS + 1% SISAL FIBRE

- Excessive WFS content reduces cementitious bonding, resulting in lower compressive strength.
- While sisal fibre provides crack resistance, the loss in effective cement paste restricts strength growth. [10]

4. At 40% WFS + 1% SISAL FIBRE

- Higher WFS content causes less cohesiveness in the mix, more voids, and segregation.
- The presence of excessive penalties from WFS might disrupt the water-cement balance, reducing strength.

Therefore, from the above result it has been found that **20% replacement of fine aggregate with waste foundry sand is found to be optimum**. The main reason behind this is as follows:

- WFS contain finer particles than normal sand, which helps to fill cavities in the concrete matrix.
- At 20% replacement, this improves particle packing without significantly altering the overall mix balance, resulting in increased density and decreased porosity. A denser concrete matrix reduces weak areas, increasing compressive strength and durability.
- The fine texture of WFS functions as a micro-filler, filling in the gaps between cement particles and aggregate.

- This enhances the interfacial transition zone (ITZ), a vital area that determines concrete strength.
- WFS may contain silica and metal oxides due to its industrial background. These reactive chemicals can contribute to secondary hydration processes, which increase strength.
- At 20% replacement, the additional hydration products fill micro cracks and voids, increasing strength while preserving the cement's role.
- At 20% WFS replacement, the mix maintains sufficient workability and cohesion, allowing for proper compaction and curing.
- Higher WFS proportions (e.g., 30% or 40%) may diminish workability, raise water demand, or result in segregation.
- WFS improve particle packing, creating a stronger bonding interface for the 1% sisal fibre, resulting in greater load transfer across fissures.
- This synergistic effect improves concrete toughness, crack resistance, and overall mechanical qualities.

Split Tensile Strength of Concrete Specimens

1. At 10% WFS + 1% SISAL FIBRE

- A little increase in strength
- The improved particle packing effect of WFS improves bonding within the concrete matrix.
- Sisal fiber bridges micro-cracks, increasing tensile strength and post-crack resistance.

2. At 20% WFS + 1% SISAL FIBRE

- Peak split tensile strength achieved.
- At this fraction, WFS optimally fills voids, increasing concrete density while maintaining adequate cohesion.
- Sisal fiber improves crack resistance by offering the optimum mix of tensile strength and endurance.[9]

3. At 30% WFS + 1% SISAL FIBRE

- Marginal decrease in strength.

- Excess WFS content may reduce the cement paste's binding efficiency.
- Although sisal fibre helps to prevent crack propagation, the reduced bonding limits tensile strength improvement.

4. At 40% WFS + 1% SISAL FIBRE

- Significant reduction in strength.
- The large volume of WFS introduces excessive fines, diminishing concrete cohesiveness and increasing brittleness.
- While sisal fiber helps to alleviate this, bonding strength loss dominates, resulting in lower split tensile strength.[10]

The main reason for the better performance of the **20% replacement of waste foundry sand** is as follows:

- At 20% WFS replacement, the fine particles effectively fill micro-voids in the concrete mix, increasing overall particle packing density.
- This denser matrix decreases weak zones, lowering internal cracks and increasing tensile strength.
- At 20% WFS, there is still enough cement paste to coat all particles properly, ensuring a strong bond.
- Higher WFS percentages (e.g., 30% or 40%) may dilute the cement paste, lowering cohesion and tensile strength.
- 1% sisal fiber serves as a reinforcing agent, bridging micro-cracks and improving the concrete's post-cracking behaviour.[12]
- Fibres distribute stress more uniformly across the matrix, which slows crack propagation and increases tensile strength.
- The ITZ (the zone between cement pastes and aggregate) is a weak region in concrete. At 20% WFS replacement, the finer particles increase ITZ density and minimize micro cracks.
- Sisal fibres strengthen this zone by increasing the weight transmission mechanism.[10]
- At 1% fiber concentration, sisal fibers are equally scattered and do not clump. This proportion maintains a balance between increasing tensile strength and ensuring adequate workability.

Conclusion

Various tests have been conducted on the constituents of the concrete, and their results have been analyzed to determine the appropriate mix proportions. Hardened concrete tests have also been performed on specimens made from the concrete. The results indicate that a 20% replacement of fine aggregate with foundry sand is the optimal percentage for replacement. Additionally, the inclusion of 1% sisal fiber helps reduce micro cracks in the concrete and improves its post-crack behavior. The use of waste foundry sand as a replacement for fine aggregate makes the concrete an eco-friendly building material. The study leads to exploring the long-term durability and performance of concrete with waste foundry sand and sisal fiber under various environmental conditions. Investigating the effects of different curing methods and durations on the mechanical properties of this eco-friendly concrete could provide valuable insights. Additionally, examining the potential of other natural fibers or industrial waste materials as partial replacements for fine aggregates could further enhance the sustainability and performance of concrete.

References

- [1] R. Siddique, G. Singh, Utilization of waste foundry sand (WFS) in concrete manufacturing. *Resources, Conservation and Recycling*, 55(11), (2011) 885-892. <https://doi.org/10.1016/j.resconrec.2011.05.001>
- [2] Y. Guney, Y.D. Sari, M. Yalcin, A. Tuncan, S. Donmez, Re-usage of waste foundry sand in high-strength concrete. *Waste Management*, 30(8-9), (2010) 1705-1713. <https://doi.org/10.1016/j.wasman.2010.02.018>
- [3] R. Kiruthigasri, T. Sathishkumar, Strengthening the Properties of Concrete using Banana Fiber and Coconut Fiber. *International Journal of Trend in Scientific Research and Development (IJTSRD)*, 4(4), (2020) 114-118.
- [4] V.S. Vairagade, S.A. Dhale, Hybrid fibre reinforced concrete–A state of the art review. *Hybrid Advances*, 3, (2023) 100035.
- [5] A.A. Okeola, S.O. Abuodha, J. Mwero, Experimental investigation of the physical and mechanical properties of sisal fiber-reinforced concrete. *Fibers*, 6(3), (2018) 53. <https://doi.org/10.3390/fib6030053>
- [6] J. Ahmad, A. Majdi, A.F. Deifalla, N. Ben Kahla, M.A. El-Shorbagy, Concrete reinforced with sisal fibers (SSF): overview of mechanical and physical properties. *Crystals*, 12(7), (2022) 952. <https://doi.org/10.3390/cryst12070952>
- [7] P. Kumar, R. Roy, Study and experimental investigation of flow and flexural properties of natural fiber reinforced self compacting concrete. *Procedia Computer Science*, 125, (2018) 598-608. <https://doi.org/10.1016/j.procs.2017.12.077>

- [8] N. Mohanraj, E. Arundhavapriya, A. Gopalan, Experimental study on hybrid concrete using steel fiber polypropylene fiber and silica fume. *International Journal of Innovative Technology and Exploring Engineering (IJITEE)*, 8(6S), (2019) 300-304.
- [9] D. Prasannan, S. Nivin, R. Rajkumar, S. Giridharan, M. Elavivekan, Comparative study on Banana and Sisal fibre reinforced concrete with conventional concrete, *International Journal of Pure and Applied Mathematics*, 118(20), (2018) 1757-1765.

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