SUSTAINABLE USE OF ALTERNATIVE MATERIALS IN RIGID PAVEMENTS

Chethan Kumar N T[1*], K E Prakash[2], Rajani V Akki[3], Ruchira S N[4]

[1]Research Scholar, Department of Civil Engineering, Shree Devi Institute of Technology, Mangalore–574 142, Visvesvaraya Technological University, Belagavi-590018, Karnataka, India.

[2]Professor, Department of Civil Engineering, Shree Devi Institute of Technology, Mangalore – 574 142, Visvesvaraya Technological University, Belagavi-590018, Karnataka, India.

[3]Assistant Professor, Department of Civil Engineering, East Point College of Engineering, Bangalore – 560 049, Visvesvaraya Technological University, Belagavi-590018, Karnataka, India.

[4]D/O Nagesh, #21, Bhagath Singh Road, Jayanagar 2nd stage, Hassan – 573 202, Visvesvaraya Technological University, Belagavi-590018, Karnataka, India.

Abstract

The growing demand for rigid pavements has resulted in an increased consumption of resources such as river sand, stone aggregates, creating environmental and sustainability concerns. To address this challenge, the present study explores the application of foundry sand with replacement for natural aggregates in M30-grade concrete. Concrete mixes were designed with varying proportions of foundry sand and tested for compressive, flexural, and split tensile strength as per IS 516:1959 guidelines. The experimental results indicate that up to 30 percent replacement of natural fine aggregates with foundry sand is feasible without compromising the strength characteristics of concrete. Flexural strength values were consistent with compressive strength trends, while mixes incorporating fly ash exhibited further improvements in performance. Conversely, higher proportions of foundry sand influenced tensile strength, indicating its limited role in high-stress applications. Laterite was also found to enhance the mechanical properties of concrete when used in suitable proportions. These suggest that industrial by-products such as foundry sand and fly ash can effectively contribute to the development of eco-friendly concrete mixes for rigid pavement construction. Such practice reduces dependency on depleting natural resources but also promote sustainable waste utilization. However, long-term durability studies under field conditions are important to validate the practical applicability of these alternative materials in large-scale pavement projects.

Keywords: Foundry sand, rigid pavements, Eco friendly pavements

Introduction

India has a road network of about 4.7 million kilometers, placing it second in the world. This network carries nearly 60 percent of goods and 85 percent of passenger traffic. Over the years, road connectivity has expanded significantly, bringing remarkable improvements in safety and design. The integration of roads connecting cities and villages has enhanced transportation efficiency, supporting the movement of both goods and passengers. Roads play important role in the growth of both developed and developing nations, and therefore must be carefully designed to meet national needs and requirements. India has the advantage of abundant locally available materials, which, if used effectively, can help reduce construction costs. There are two primary types of pavements: flexible and rigid. Although the initial cost of rigid pavements is higher compared to flexible pavements, their lifecycle cost proves to be more economical. Experts emphasize that pavement selection should be based on lifecycle costing rather than initial expenditure alone. Furthermore, the initial cost of rigid pavements can be reduced by incorporating alternative materials, such as partial replacement of natural sand with foundry sand, making the solution both economical and resource-efficient. Several researchers have explored the feasibility of incorporating waste foundry sand in concrete as a sustainable alternative to natural fine aggregates. Bhoite [1] studied the combined effect of waste foundry sand and steel fibers, reporting improvements in mechanical properties. Mohod [2] highlighted its application in rigid pavements, emphasizing economic and environmental benefits. Similarly, Suman Rani and Bishnoi [3] demonstrated the beneficial use of foundry sand in cement concrete. Siddique et al. [7] and Singh and Siddique [5] investigated strength and durability aspects, showing that foundry sand can enhance abrasion resistance and long-term performance. Manoharan et al. [6] and Prabhu et al. [4] confirmed that replacement with foundry sand yields comparable strength to conventional mixes, while Sandhu and Siddique [9] highlighted its effectiveness in self-compacting concrete. Recent studies by Kumar et al. [11] and García Del Angel et al. [12] further validated the suitability of foundry sand in modern concrete applications, including high-performance and self-compacting mixes. Collectively, these studies indicate that foundry sand is a promising supplementary material that can conserve natural resources and support sustainable concrete production.

Materials:

Cement (OPC 43 grade)

The cement used is OPC of 43 grade, conforming to the specifications of IS 8112:1989. OPC 43 grade is widely used types of cement in general civil engineering construction due to its balanced properties of strength and workability. It attains a minimum compressive strength of 43 MPa at 28 days, making it suitable for RC works, pavements, precast applications, and other structural elements where moderate strength requirements are essential.

This grade of cement is preferred in pavement-quality concrete because it ensures adequate early strength for construction operations, along with long-term durability. In addition, OPC 43 grade provides better resistance to cracking and shrinkage when compared with higher grades, making it a cost-effective choice for rigid pavement applications.

Table.1 Physical processions of Cement

Sl. No.	Test Conducted	Obtained Values
1	Specific gravity	3.12
2	Initial Setting Time	55 min
4	Normal Consistency	33%
5	Fineness	4%

Fine Aggregate

The natural sand used for the experimental work was locally sourced and confirmed to conform to Grading Zone I as per IS: 383-1970, *Specification for Coarse and Fine Aggregates from Natural Sources for Concrete*. Zone I sand is characterized by relatively coarser particles, which contribute to improved strength development and reduced water demand in concrete mixes. Physical properties such as specific gravity, bulk density, fineness modulus, and water absorption were determined to ensure compliance with the standard specifications. The coarser grading of Zone I sand makes it particularly suitable for producing high-strength concrete, as it provides better packing density and minimizes voids in the matrix. The use of such well-graded natural sand ensures good workability, effective bonding with cement paste, and adequate durability for rigid pavement applications.

Table 2 Physical processions of Fine Aggregate

SL.NO	Properties	Obtained Values
1	Specific Gravity	2.62
2	Fineness modulus	5.35%
3	Bulking of Sand	41.2% at water content 9%

Table 3 Sieve analysis of Natural sand

Sieve size	Cumulative		Zone as per IS 383-1970			
	% Weight retained	% Passing	Zone I	Zone II	Zone III	Zone IV
4.75 mm	3.75	**96.24**	**90-100**	90-100	90-100	95-100
2.36 mm	10.51	**85.73**	**60-100**	75-100	85-100	95-10
1.18 mm	29.85	**55.86**	**30-70**	55-90	75-100	90-100
600 μ	32.56	**21.32**	**15-34**	35-59	60-75	80-100
300 μ	20.52	**5.35**	**5-20**	8-30	12-40	15-50
150 μ	2.52	**0.51**	**0-10**	0-10	0-10	0-15

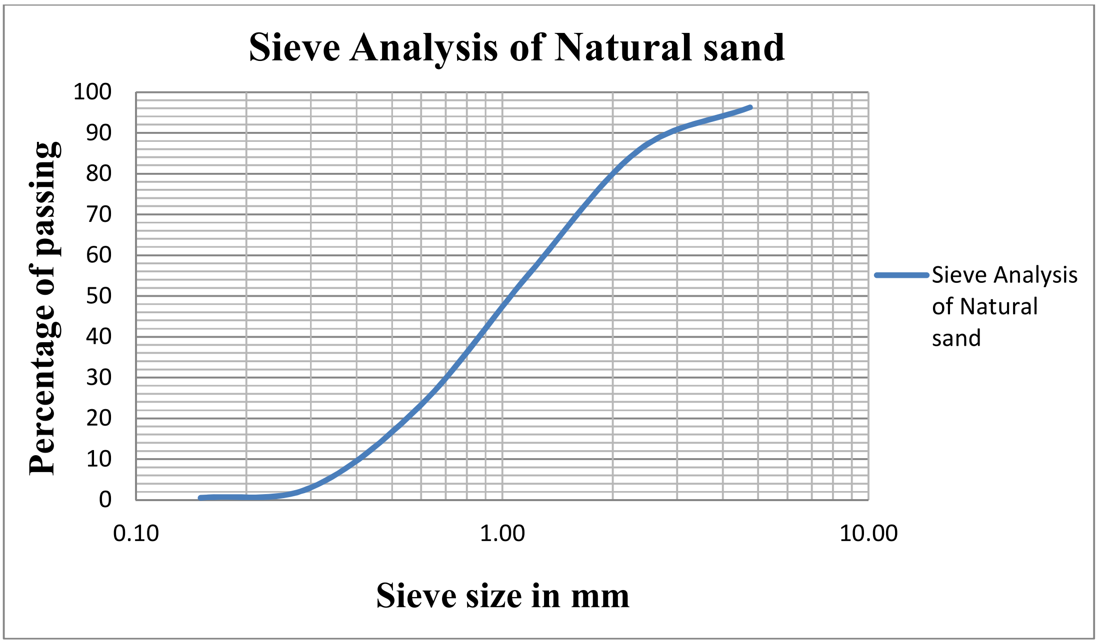

Fig 1 Sieve analysis of natural sand

Foundry sand

River sand, commonly referred to as local sand, is rich in silica and widely used due to its superior thermal conductivity. In foundries, silica sand is utilized for the preparation of moulds, where it is known as foundry sand. This sand undergoes multiple recycling and reuses within the foundry process, typically through washing. Once it loses its functional properties, it is discarded, often creating disposal and environmental challenges [1].

Incorporating foundry sand into construction and engineering applications offers a sustainable solution to these issues. Foundry sand is characterized by its cleanliness, uniform particle size, and high-quality silica content [2]. It is primarily used in casting processes for both ferrous (iron and steel) and non-ferrous (copper, aluminum, brass) metals, where it is bonded to form moulds and patterns. After the casting process, the shake-out sand can often be reclaimed and reintroduced into the foundry cycle.

The utilization of spent foundry sand in concrete has shown potential to enhance strength and durability, while simultaneously addressing environmental concerns by reducing waste and conserving natural resources[3] [4].

Table 4 Physical Properties of Foundry sand

Sl. No.	Properties	Obtained Values
1	Specific Gravity	2.6
2	Fineness modulus	5.106%
3	Bulking of Sand	17.39% at water content 6%

Table 5 Sieve analysis of foundry sand

Sieve size	Cumulative		Zone as per IS 383-1970			
	% Weight retained	% Passing	Zone I	Zone II	Zone III	Zone IV
4.75 mm	0	**100**	**90-100**	90-100	90-100	95-100
2.36 mm	0.5	**98.5**	**60-100**	75-100	85-100	95-10
1.18 mm	1.5	**89.5**	**30-70**	55-90	75-100	90-100
600 µ	47.7	**50.3**	**15-34**	35-59	60-75	80-100
300µ	29	**18.9**	**5-20**	8-30	12-40	15-50
150µ	24.7	**1.02**	**0-10**	0-10	0-10	0-15

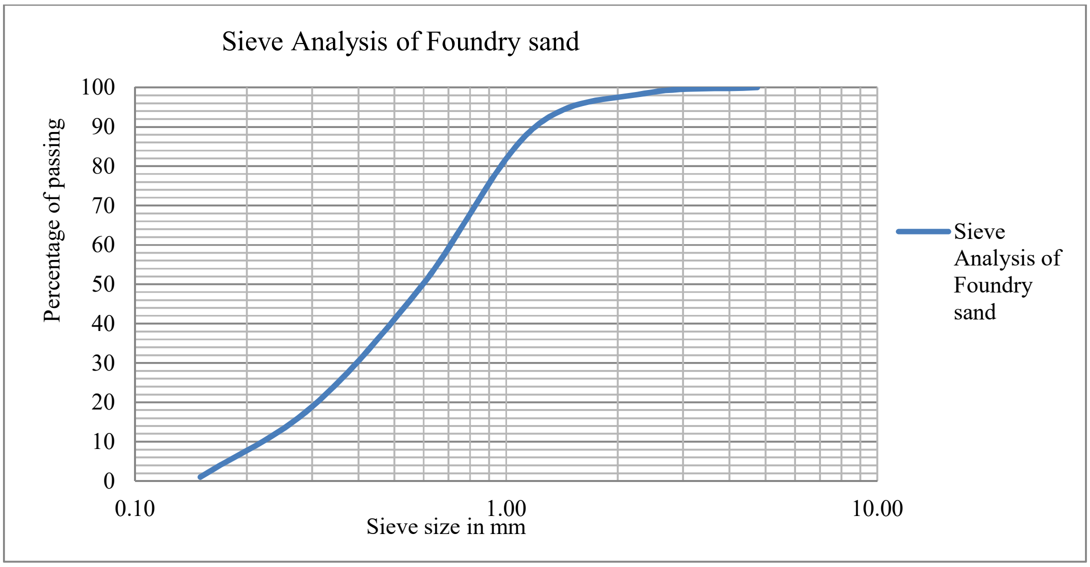

Fig 2 Sieve analysis of foundry sand

Coarse Aggregate

The coarse aggregates used in this experimental study were locally procured and tested to ensure compliance with IS: 383-1970. Crushed angular aggregates of nominal size 20 mm were selected, as they are commonly used in rigid pavement concrete for achieving adequate strength and durability. The aggregates were clean, hard, and free from dust, clay, organic matter, and other deleterious substances that might affect the performance of concrete. The physical properties were determined in accordance with IS: 2386 (Part I–IV).

Table 6 Physical Processions of coarse aggregate

SLNO	Properties	Obtained value
1	Specific Gravity	2.64
2	Bulk density 1. Loose state 2. Compact state	 1.49 gm/cc 1.622 gm/cc
3	Water absorption	0.43 %
4	Fineness modulus	8.03 %
5	Impact value	21.4%
6	Crushing value	27.32%

Mix design

The concrete used in this study was designed for a characteristic compressive strength of M30 grade, following the guidelines of IS: 10262-1982. The target mean strength was determined by incorporating the standard deviation as prescribed in the code. A water–cement ratio of 0.42 was adopted to attain the strength and durability requirements.

The final mix proportions for M30 grade concrete, along with adjustments for partial replacement of fine aggregates with foundry sand, are provided in the Annexure. These proportions formed the basis for casting the test specimens used in the experimental program, which included compressive strength, flexural strength, and split tensile strength tests.

Table 7 Mix design contents (kg/m³)

Water	Cement	Fine aggregate	Coarse aggregate
91.58	537.4 kg/m³	556.96 kg/m³	1065.49 kg/m³
Mix proportions of M30 grade concrete			
1:1.04:1.98			

Fresh concrete was prepared using conventional ingredients. Then natural sand was replaced by foundry sand with various percentages. Then it is used to cast cubes, cylinders and beams. They were cured at 3 days 7 days and 28 days and tested.

Fresh concrete properties

The results of the slump tests and compaction tests are carried out on the fresh concrete, results gives an indication of the workability of the concrete for a water cement ratio of 0.35, a maximum slump of 10 mm is observed.

Table 8 Slump and Compaction factor value

Type of concrete	Maximum slum	Compaction factor
NC	10 mm	0.81

4.4 Hardened concrete properties

The hardened properties or mechanical properties of the concrete such as compressive strength, spilt tensile and flexural strength were determined at the ages of 3 days, 7 days and 28days.

4.4.1 Compressive strength

The factual test conducted according to IS : 516-1959. The cubes were tested at the age of 3 days, 7 days and 28 days. The cubes were tested on compression testing machine. The factual strength of concrete with local sand and different percentage of foundry sand replaced in natural sand are listed in **Table 4.8** at the age of 3 days 7days and 28 days. The maximum factual strength is achieved at 30% of substitution of river sand with used foundry sand.

Figure 4.3 shows the average factual strength at 3 days, 7days and 28 days of conventional concrete and substitution of fine aggregate with used local and waste sand .

Table 9 Compressive Strength of Cubes (150×150×150mm) at3, 7&28 days

Type of concrete	Average compressive strength (N/mm²)		
	3 days	7 days	28 days
NC	27.99	33.07	42.38
20 % FS	30.09	36.67	43.44
30 % FS	31.38	37.87	46.57
40 % FS	28.19	32.77	39.39

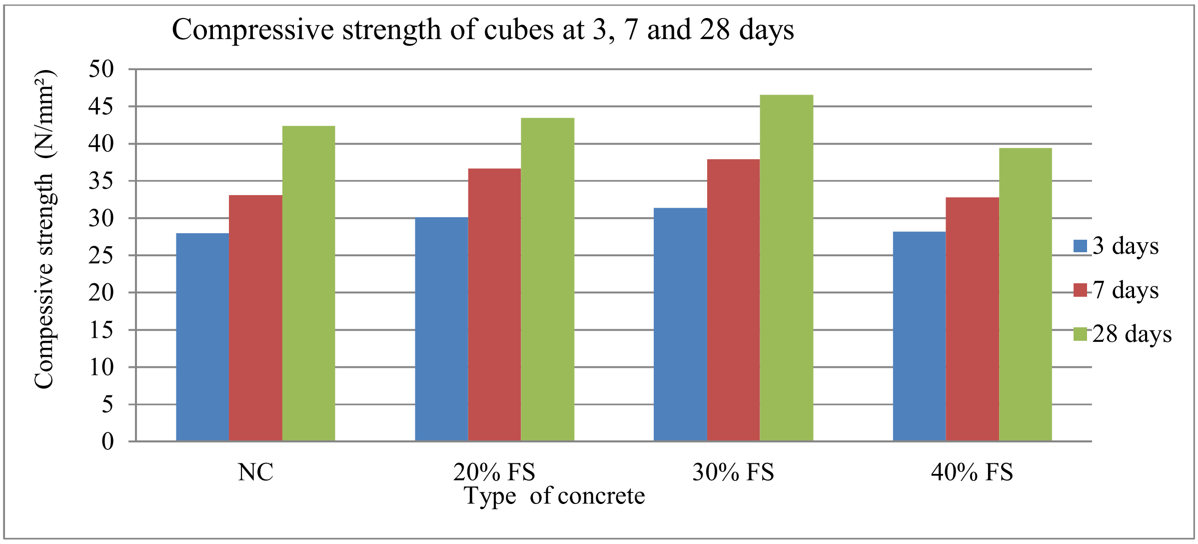

Figure 3 Compressive strength of cubes at 3 days, 7 days and 28 days

4.4.2 Split Tensile Strength

The factual strength of concrete with natural sand and different percentage of foundry sand replaced in natural sand are listed in **Table 4.9** at the age of 3 days 7days and 28 days. The maximum split tensile strength is achieved at 20% replacement of river sand with used local sand.

Fig 4.4 shows the average split tensile strength at 3 days, 7days and 28 days of conventional concrete and replacement of fine aggregate with used local sand .

Table 10 Split tensile strength of cylinder (150×300) for M30 mix at 3,7,28 days.

Type of concrete	Average split tensile strength (N/mm²)		
	3 days	7 days	28 days
NC	2.05	2.54	2.98
20 % FS	2.97	3.437	3.84
30 % FS	2.92	3.17	3.56
40 % FS	1.92	2.62	2.9

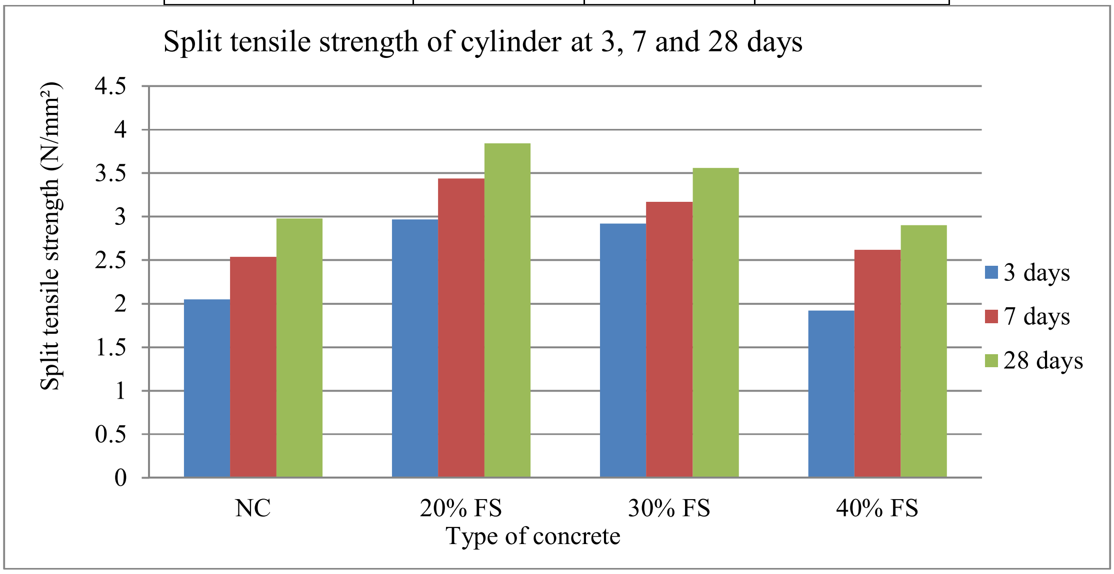

Fig 4 Split tensile test of cylinder at 3 days, 7 days and 28 days

4.4.3 Flexural Strength

. The bend strength of concrete with local sand and different percentage of local sand replaced in natural sand are listed in **Table 4.10** at the age of 3 days 7days and 28 days. Decrease in bend strength of concrete with increase in used local sand.

Fig 4.5 shows the average flexural strength at 3 days, 7days and 28 days of conventional concrete and substitution of sand with used locally available sand.

Table 11 Flexural strength of beam (150×150 ×700) for M30 mix at 3,7,28 days.

Type of concrete	Average flexural strength (N/mm²)		
	3 days	7 days	28 days
NC	2.92	3.25	4.26
20 % FS	2.93	3.37	4.44
30 % FS	2.92	3.20	4.01
40 % FS	2.75	3.02	3.73

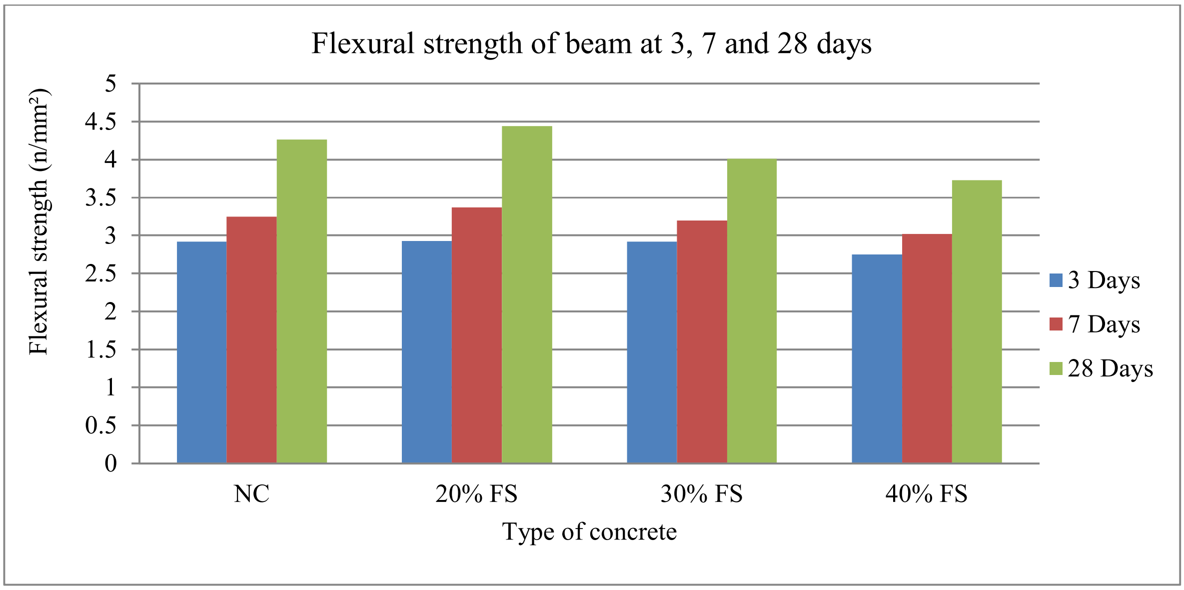

Figure 5 flexural strength of beam at 3 days, 7 days and 28 days

Conclusions

From the present study, the conclusions are as follows

1. Partial replacement of fine aggregate with waste foundry sand improves the strength of concrete up to an optimum level. The max. compressive strength was achieved at 30% replacement, while the max. split tensile strength was observed at 20% replacement.
2. Beyond these optimum levels, the use of sand tends to reduce the bonding and cohesive properties of concrete matrix, which affect its long-term performance.
3. The incorporation of waste foundry sand in concrete not only enhances mechanical properties within the optimum range but also provides an eco-friendly solution to waste disposal, thereby reducing environmental impacts and conserving natural resources.

Recommendations for Future Work

1. Detailed investigations on the long-term durability properties of concrete incorporating foundry sand, such as resistance to sulphate attack, chloride penetration, and freeze-thaw cycles, are necessary to ensure field applicability.
2. Large-scale field trials for rigid pavement construction should be carried out to validate the laboratory results and assess real-world performance under traffic loading and environmental conditions.

3. Microstructural studies, SEM and X-ray diffraction (XRD), are recommended to better understand the bonding mechanism between cement paste and foundry sand particles.
4. Further research on combining foundry sand with other materials such as fly ash, GGBS, or silica fume can help develop high-performance and sustainable concrete mixes.

REFERENCES

[1] Bhoite V R, "*Mechanical properties of concrete incorporating waste foundry sand and steel fibre*'', International Journal of Engineering, Science and Technologies (IJRESTs) Civil Engineering, ISSN 2395-6453, pp.34-42, 2016.

[2] M.V. Mohod, "*Application of Waste Foundry Sand in Rigid Pavement*", International Conference on Science and Technology for Sustainable Development (ICSTSD), pp.78-84, 2016.

[3] Suman Rani and Mr.Mangandeep Bishnoi, "*Beneficial Use Of Waste Used Foundry Sand In Cement Concrete*'',International Journal of Technical Research (IJTR), Vol.5, Issue.1, pp.56-64, Mar-Apr 2016.

[4] G. Prabhu, J. H. Hyun, and Y. Y. Kim, "Effects of foundry sand as a fine aggregate in concrete production," *Construction and Building Materials*, vol. 70, pp. 514–521, 2014.

[5] G. Singh and R. Siddique, "Abrasion resistance and strength properties of concrete containing waste foundry sand (WFS)," *Construction and Building Materials*, vol. 28, pp. 421–426, 2012.

[6] T. Manoharan, D. Laksmanan, K. Mylsamy, P. Sivakumar, and A. Sircar, "Engineering properties of concrete with partial utilization of used foundry sand," *Waste Management*, vol. 71, pp. 454–460, 2018.

[7] R. Siddique, Y. Aggarwal, P. Aggarwal, E. Kadri, and R. Bennacer, "Strength, durability, and micro-structural properties of concrete made with used-foundry sand (UFS)," *Construction and Building Materials*, vol. 25, no. 4, pp. 1916–1925, 2011.

[8] G. Singh, R. Siddique, R. Belarbi, K. Ait-Mokhtar, and Kunal, "Comparative investigation on the influence of spent foundry sand as partial replacement of fine aggregates on the properties of two grades of concrete," *Construction and Building Materials*, vol. 83, pp. 216–222, 2015.

[9] R. K. Sandhu and R. Siddique, "Strength properties and microstructural analysis of self-compacting concrete incorporating waste foundry sand," *Construction and Building Materials*, vol. 225, pp. 371–383, 2019.

[10] D. Sangavi and K. A. Senthil, "Utilisation of foundry sand in concrete – A review," *International Research Journal of Multidisciplinary Technovation*, vol. 1, no. 6, pp. 383–386, 2019.

[11] R. S. Kumar, P. Devarajan, D. S. Vijayan, A. S. Kumar, A. S. Kadavan, and R. Rajesh, "Performance assessment and engineering behaviour of cement concrete with partially replaced foundry sand as fine aggregate," *IOP Conf. Ser.: Earth and Environmental Science*, vol. 1130, no. 1, p. 012007, 2023.

[12] P. Thakur and K. Singh, "Performance of concrete using waste foundry sand and paper sludge ash," *International Journal of Civil Engineering and Technology*, vol. 9, no. 8, pp. 1105–1114, 2018.