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Mechanical characterization and durability studies on concrete developed with M-Sand and River Sand

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ABSTRACT

The over-exploitation of river sand for construction has led to significant environmental concerns, prompting bans and the search for viable alternatives such as Manufactured Sand (M-Sand). This study evaluates the feasibility of M-Sand as a substitute for river sand in concrete production by comparing their physical, mechanical, and durability properties. Physical property assessments include grading and specific gravity. Mechanical properties such as compressive and split tensile strengths were evaluated to determine the structural integrity of the concrete. Durability tests, including the Rapid Chloride Penetration Test (RCPT), alkalinity test, and impact resistance test, were conducted to assess the concrete's resilience to environmental challenges. This study investigated M20, M25, and M30 grades of concrete using river sand and M-Sand. Compressive strengths for M-Sand were slightly lower than river sand but remained within acceptable ranges: 23.80 N/mm^2 (M20), 27.50 N/mm^2 (M25), and 33.85 N/mm^2 (M30). Split tensile strengths followed a similar trend. Durability tests, including RCPT, showed comparable resistance to chloride penetration, with all mixes rated "Very Low." Alkalinity levels were maintained between 9 and 12, protecting steel reinforcement. Impact resistance and ductility were also comparable, with an average ductility index of 1.289. M-Sand is confirmed as a sustainable alternative to river sand.

Keywords: M-sand; River Sand; Compressive strength; RCPT; Alkalinity test.

1. INTRODUCTION

The construction industry heavily depends on natural resources, particularly river sand, which is comprehensively used as a fine aggregate in concrete production. However, the over-exploitation of river sand has led to severe environmental degradation, including riverbed erosion, habitat destruction, and reduced groundwater levels. These environmental concerns, coupled with the increasing scarcity and cost of river sand, have prompted the need for sustainable and economically viable alternatives. Many state governments in India have banned the usage of river sand for construction activities to prevent the damage of environmental degradation. The governments have suggested using M-sand instead of river sand. Builders and contractors have started to use M-sand due to government orders, non-availability, and the high cost of river sand. However, many clients are hesitant to construct their buildings using M-sand. This situation raises a hypothetical question: Is M-sand suitable for concrete production and construction? Manufactured Sand (M-Sand) is an artificial aggregate made by crushing hard granite stones. The production process of M-Sand is designed to ensure that the sand meets the specifications required for use in concrete and other construction applications. The process involves several stages, each contributing to the overall quality and consistency of the final product. M-Sand is produced by crushing hard granite stones, creating angular particles that are cubically shaped and well-graded, providing enhanced properties for concrete production. The use of M-Sand not only addresses the environmental concerns associated with river sand extraction but also ensures a consistent supply of high-quality sand for construction purposes.

Compressive strength is a significant parameter to verity the suitability of M-sand for the concrete production and construction activities. Many researchers have reported that compressive strength of concrete made with M-sand and the compressive strength of concrete made with partial replacement of M-sand produces comparable compressive strength compared to the concrete made with river sand [1–4]. Qingling MENG *et al.* [5] have described that compressive strength and flexural fatigue strength were high when the M-sand replacement

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percentage is in the range of 30–70%. In addition some researchers have reported that compressive strength, flexural strength and split tensile strength of the concrete made with partial replacement of M-sand with river sand could produce similar results until 60% replacement, the strength degradation was concluded if the replacement percentage is increased more than 60% [6, 7]. MANJUNATHA *et al.* [8] have concluded that 13.2% increase in flexural strength 18.88% increase in compressive strength and of concrete when concrete made up of 50% replacement of M-sand along with silica fume. Durability characteristics of concrete made with the M-sand was analysed by researchers and reported that 2–8% loss in compressive strength due to acid attack, chloride attach and sulphate attack when correlated to the concrete made with river sand [9]. The results of water permeability tests are comparable with the nominal concrete [10]. Other properties such as modulus of elasticity, impact resistance and sorptivity results also produced as comparable results of the river sand [11]. The researchers have reported that M-sand has been used in different types of concretes and different applications such as self-compacting concrete [12–14] high performance concrete [7], geopolymer concrete [15], geoplymer blocks [16], geoplymer lightweight concrete [17], jute-fiber based reinforced concrete [18] cement mortar [19–21] reinforced concrete spun pipes [22], pavements [23] etc. RAJENDRAN *et al.* [24] have investigated concrete made with granite waste and alccofine using M-sand. HAMADA *et al.* [25–27] have studied the behavior of M-sand in comparison with desert sand. The literature review confirms that M-sand, whether used entirely or as a partial replacement, achieves compressive strength and durability properties comparable to those of river sand in concrete. Researchers have successfully utilized M-sand in various concrete applications, validating its suitability as a sustainable alternative to river sand. However, previous reports have not comprehensively studied the physical properties (such as grading, fineness modulus, and specific gravity), mechanical properties (such as compressive strength and split tensile strength with various proportions), and durability properties (such as RCPT test, alkalinity test, and impact resistance test) of M-sand. This study aims to investigate these physical, mechanical, and durability properties of concrete made with M-sand, which have not been explored in earlier research.

2. PHYSICAL PROPERTIES

2.1. Grading

Grading of sand refers to the distribution of particle size distribution within a given sample, which significantly influences the properties and performance of concrete. Sand grading is typically categorized into well-graded, poorly graded, and uniformly graded sand, each having distinct characteristics and applications. The grading of sand influences the features of fresh and hardened concrete, such as workability, strength, durability, economy, and shrinkage. Properly graded sand helps control shrinkage and reduce the risk of cracking. Proper grading of sand minimizes internal stress and prevents the development of micro-cracks during drying and curing. The Indian Standard IS 383-2002 [28] specifies the requirements for the grading of fine aggregates, including natural sand, crushed gravel sand, and crushed stone sand, for use in concrete. This standard categorizes fine aggregates into four grading zones, each with specific particle size distribution requirements to ensure optimal performance in concrete mixes. Understanding these grading zones is crucial for producing high-quality concrete that meets strength, durability, and workability requirements. Table 1 shows the guidelines of grading of sand as per IS 383-1970 [28]. Grading Zone I represents coarse sand with larger particle sizes, making it highly suitable for concrete requiring high strength and bulk density. The fineness modulus (FM) for sand in this zone typically ranges from 3.4 to 3.6. This type of sand is characterized by its ability to provide excellent workability with less water due to the larger particle sizes, which facilitate better compaction and reduced voids within the concrete mix. Consequently, concrete made with Grading Zone I sand tends to exhibit enhanced strength and durability, making it ideal for structural applications where high load-bearing capacity is essential.

Grading Zone II includes moderately coarse sand, which is the most commonly used type for general concrete work. The fineness modulus for this zone ranges from 2.8 to 3.4. Sand in Grading Zone II offers a good balance between workability and strength; create it versatile for a varied range of concrete applications. It provides sufficient particle interlocking, which enhances the mix's overall stability and compaction. This zone's sand is suitable for constructing floors, beams, columns, and other structural elements where balanced performance is required. Grading Zone III comprises finer sand with smaller particle sizes, with a fineness modulus ranging from 2.2 to 2.8. This sand is particularly useful for applications requiring a smoother finish, such as plastering and other fine concrete work. Because of the higher surface area of the finer particles, sand from Grading Zone III requires more water to achieve the desired workability. While it may not provide the same level of strength as coarser sands, its ability to produce smooth, aesthetically pleasing surfaces makes it valuable for finishing applications and detailed concrete elements. Grading Zone IV consists of very fine sand, with the fineness modulus ranging from 1.4 to 2.2. This type of sand is used in specialized applications like fine plaster,

Table 1: Guidelines of grading of sand as per IS 383-2002.

IS SIEVE SIZE	PERCENTAGE PASSING FOR			
	GRADING ZONE I	GRADING ZONE II	GRADING ZONE III	GRADING ZONE IV
10 mm	100	100	100	100
4.75 mm	90-100	90-100	90-100	95-100
2.36 mm	60-95	75-100	85-100	95-100
1.18 mm	30-70	55-90	75-100	90-100
600 µm	15-34	35-59	60-79	80-100
300 µm	5-20	8-30	12-40	15-50
150 µm	0-10	0-10	0-10	0-15
Classification	Course Sand	Medium sand	Mild sand	Fine Sand

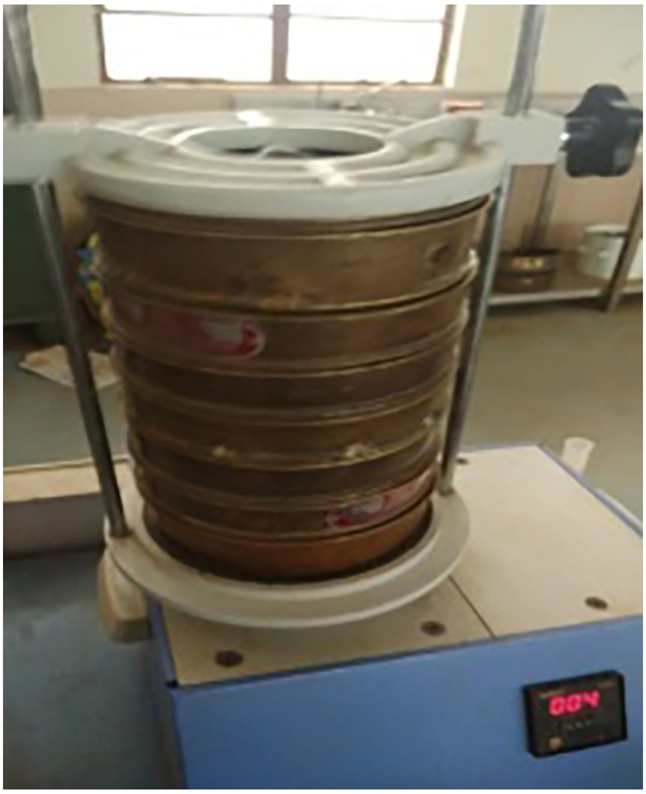

Figure 1: Automatic sieving machine.

grouting, and other contexts where high fluidity and smooth finishes are required. The very fine particles have a large surface area, leading to high water demand to maintain workability. While not typically used for structural concrete due to its lower strength, Grading Zone IV sand is essential for applications that need detailed and precise finishes, ensuring that the final product meets high standards of appearance and texture.

IS 383-2002 [28] specifies the percentage passing for each sieve size for the four grading zones. The standard provides a clear distribution range for each zone to ensure the sand used in concrete mixes is consistent and meets the required specifications. Sieve analysis has performed for both M-sand and river sand to determine the grading of aggregates. Figure 1 shows an automatic sieving machine where the sieve analysis was performed. Sieve analysis results are shown in Table 2. Sieve analysis results can be interpreted easily when it is viewed graphically and grading curves are widely employed for this reason. In the grading graph, the ordinates represent cumulative percentage passing and abscissa shows the sieve opening plotted on logarithmic scale. By using this

Table 2: Grading of river and M-sand.

SIEVE SIZE	WEIGHT OF SAND RETAINED (grams)		CUMULATIVE WEIGHT RETAINED (grams)		CUMULATIVE PERCENTAGE RETAINED (%)		PERCENTAGE PASSING (%)	
	RIVER SAND	M-SAND	RIVER SAND	M-SAND	RIVER SAND	M-SAND	RIVER SAND	M-SAND
10 mm	0	0	0	0	0	0	100	100
4.75 mm	0	0	0	0	0	0	100	100
2.36 mm	3	10	3	10	0.27	0.99	99.73	99.01
1.18 mm	110	160	137	175	12.51	17.4	87.49	82.6
600 m	215	240	372	415	33.97	41.3	66.03	58.7
300 m	510	320	912	735	83.28	73.14	16.72	26.86
150 m	140	185	1073	920	97.99	91.54	2.01	8.46
Pan	22	85	1095	1005	100	100	0	0
Total	**1000**	**1000**			**328.02**	**324.37**		

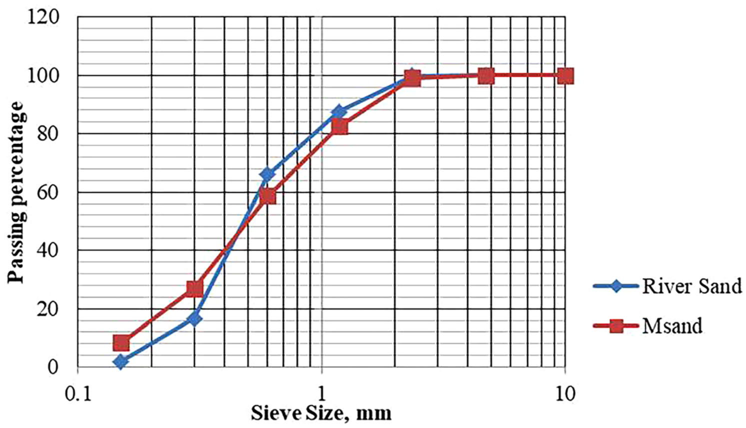

Figure 2: Grading of river sand and M-sand.

type of graph, it shows whether the given sample is too coarse or too fine or defective in particular size. Moreover, grading zones can be identified using these plots.

The graph (Figure 2) shows the sieve analysis Results of River and M-Sand. The x-axis represents the sieve size on a logarithmic scale, ranging from 0.1 to 10, and the y-axis represents the passing percentage, ranging from 0 to 120. It is observed that the higher passing percentage (80–100%) from 10 mm sieve size to 1.18 sieve size. It indicates that more percentage of sand particles below the range of 1.18 mm in size. It is observed that 20–80% of sand particles were passed in the sieve sized 600 m to 300 m sieve which indicated most of the sand particles were in this range. River sand shows a slightly steeper curve in this range, suggesting a quicker transition to higher passing percentages compared to M-Sand. It is observed that less than 20% of sand samples only passing in the sieve size of 150 m means that the sample contains less percentage in this size range. The results of river sand and M-sand were compared with the standards of IS 383-2002 [28] grading zones from I to IV, as shown in Figure 3. It is evident that the results of the sand samples closely coincide with the results of grading zone II. The classification of grading zone II is medium sand. Hence, it can be concluded that river sand and M-sand fall into the same category zones.

2.1.1. Fineness modulus

Fineness Modulus (FM) is an empirical number that is obtained by summing the cumulative percentages of aggregate retained on each of the standard sieves and dividing by 100 (Eq.1 and Eq.2). It provides a single figure that represents the average particle size of the aggregate. For sand, the FM typically ranges from 2.8 to 3.6. Fineness modulus is an important property for concrete mix design, workability, strength, durability, consistency, and economics. Choosing the appropriate FM of fine aggregate will benefit all the above-mentioned aspects.

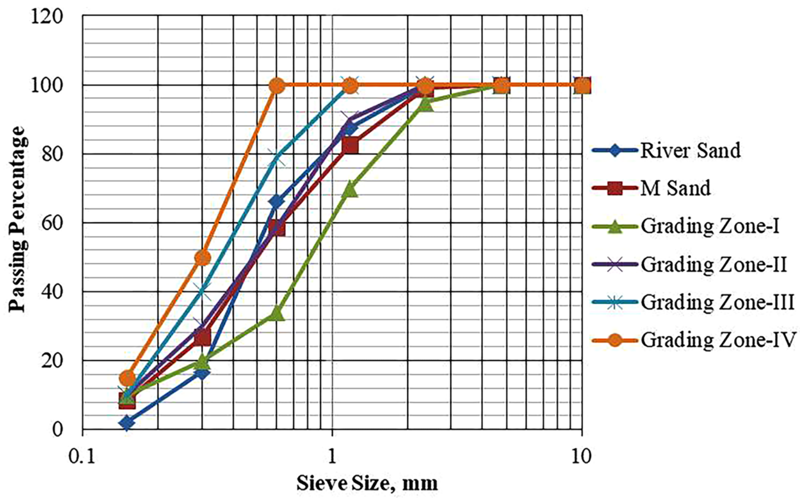

Figure 3: Grading of river sand and M-sand compared with the standard zones in IS:383:2002.

Fineness modulus of River sand is:

$$FM = \frac{Cumulative\ percentage\ retained}{100} = \frac{328.02}{100} = 3.28 \quad (1)$$

FM of M-sand is:

$$FM = \frac{Cumulative\ percentage\ retained}{100} = \frac{324.07}{100} = 3.24 \quad (2)$$

It is determined from the Eq.1 and Eq.2 that the FM of river sand is 3.28 and the FM of M-sand is 3.24. The FM of M-sand is very close to the fineness modulus of River sand. The FM also indicates that the River sand and M-sand falls in the category of grading zone–II.

2.2. Specific gravity

Specific gravity (SG) or relative gravity is a measure of the density of a material compared to the density of water. For sand, the specific gravity typically ranges between 2.5 and 2.9. It is calculated using the formula (Eq.3).

$$Specific\ Gravity\ (SG) = \frac{Weight\ of\ sand\ in\ air}{Weight\ of\ sand\ in\ air - weight\ of\ sand\ in\ water} \quad (3)$$

This value is dimensionless and helps in understanding the relative density of the sand particles. SG is an important property of sand that directly influences concrete mix design, strength, density, workability, consistency, durability, quality and economics.

The standard procedure of IS 2386 (Part III) – 1963 (Reaffirmed 2002) was followed for the conduction of SG test. SG test were performed over five different samples which are River sand, M-sand, the combination of 25% River sand and 75% of M-sand, the combination of 50% River sand and 50% M-sand and the combination of 75% River sand and 25% M-sand. Table 3 provides the SG results and calculations for different sand samples: river sand, M-sand, and various mixtures of river sand and M-sand.

$$G = \frac{w_2 - w_1}{(w_2 - w_1) - (w_3 - w_4)} \quad (4)$$

The SG in the table 3 is calculated using the equation 4. The SG of river sand is 2.75, which is within the typical range for standard natural sand 2.6 to 2.8 which indicates relatively high density and strength. The SG of M Sand is 2.68, slightly lower than that of river sand. M-sand has a lower density compared to river sand,

Table 3: The results of specific gravity experiments.

CALCULATIONS	RIVER SAND	M-SAND	25%R, 75%M	50%R, 50%M	75%R, 25%M
Weight of pycnometer (w_1) (kg)	0.620	0.630	0.62	0.62	0.62
Weight of pycnometer + sand (w_2) (kg)	0.842	0.885	0.82	0.825	0.825
Weight of pycnometer + sand + water (w_3)(kg)	1.653	1.685	1.635	1.664	1.645
Weight of pycnometer + water (w_4) (kg)	1.512	1.525	1.51	1.535	1.515
Specific Gravity (G)	**2.75**	**2.68**	**2.67**	**2.69**	**2.73**

which might affect the concrete mix's density and strength slightly. The SG of 25% river sand with 75% M-sand is 2.67. The SG is slightly lower than that of pure river sand and pure M-sand. This suggests a more balanced combination of particle sizes, which may affect the density and workability of the concrete mix. The SG of 50% river sand with 50% M-sand is 2.69. The SG is higher than that of M-sand but slightly lower than that of river sand which indicates that a well-balanced mixture, providing a good combination of density and strength for concrete. The SG of 75% river sand with 25% M-sand is 2.73. The SG is nearby to that of pure river sand. It suggests that the mixture maintains most of the properties of river sand, providing good density and strength.

Pure river sand has a higher SG compared to M-sand, and among the mixture of River sand and M sand, 25% river sand and 75% M-sand shows a lower SG. However, it was observed that the SG of M-sand is very close to the SG of river sand. As well, the different mixture of river sand and M-sand also attained a close SG value of River sand. It designates that the M-sand also might offer a good balance of density and strength for concrete applications.

3. MECHANICAL PROPERTIES

3.1. Compressive strength

Compressive strength is among the most crucial characteristic of concrete. It refers to the ability of concrete to withstand compressive loads. Compressive strength is crucial because it is directly related to the durability and structural integrity of a concrete structure. Compressive strength determines the load-bearing capacity of concrete structures. It ensures that buildings, bridges, and other constructions can safely support both dead loads (own weight of structure) and live loads (furniture, people, vehicles, etc.). Adequate compressive strength is essential for the safety of the structure and its occupants. A structure with insufficient strength is at risk of failure, leading to potential hazards and loss of life. Higher compressive strength typically leads to better durability. Strong concrete is more resistant to weathering, chemical attacks, abrasion, and other environmental factors, thus prolonging the lifespan of the structure. Measuring compressive strength is a primary method of quality control for concrete. It ensures that the concrete mix used meets the required specifications and standards, reducing the likelihood of structural issues. Using concrete with appropriate compressive strength can lead to economic savings. Over-designing (using higher strength concrete than necessary) can lead to increased costs. Understanding the compressive strength of concrete allows engineers to design more efficient and innovative structures. It enables the use of thinner sections and longer spans, leading to material savings and more aesthetic designs.

Table 4 shows the mix design proportions of concrete grades M20, M25, and M30. The proportions of the materials for each grade are also included in the table. To verify the suitability of M-sand as a replacement for river sand in structural applications, compressive strength tests were conducted on 90 cube samples of 150 mm each. 45 samples were tested for 14-day compressive strength, and the remaining 45 samples were tested for 28-day compressive strength. The typical arrangement of the compressive strength test using a 2000 kN capacity automatic compressive test machine is shown in the Figure 4. The test results, which are the average results of three cube samples, are tabulated in Table 5.

The compressive strength results indicates that the concrete cubes made of M-sand also produces equal compressive strength related to the concrete cubes made of river sand. Figure 5 shows compressive strength test results of 14 days and 28 days of concrete cubes made from river sand and M-sand and the combination of River sand and M-sand. It is observed that the river sand produces higher compressive strength when compared to the M-sand. However the M-sand results also can be comparable to the results of river sand. Meanwhile the combination of river sand and M-sand also produces the equivalent compressive strength. The findings show that M-sand can be utilised as an efficient alternative for river sand in concrete mixtures. It provides comparable

Table 4: Concrete mix design.

GRADE	CEMENT (kg)	FINE AGGREGATE (kg)	COARSE AGGREGATE (kg)	WATER (l)	PROPORTION
M20	325	527	986	186	1:1.62:3.03:0.57
M25	355	450	750	186	1:1.26:2.11:0.52
M30	385	420	630	186	1:1.09:1.63:0.48

Figure 4: Compressive strength test on compression testing machine.

Table 5: Compressive strength results (N/mm^2).

GRADE OF CONCRETE	RIVER SAND		M-SAND		25%R, 75%M		50%R, 50%M		75%R, 25%M	
	14 DAYS	28 DAYS	14 DAYS	28 DAYS	14 DAYS	28 DAYS	14 DAYS	28 DAYS	14 DAYS	28 DAYS
M20	16.08	24.55	15.60	23.80	14.65	22.50	15.35	23.60	15.85	24.35
M25	19.60	28.65	19.20	27.50	17.65	25.20	17.85	25.45	18.70	26.50
M30	23.45	34.35	22.70	33.85	20.75	32.20	21.45	32.60	22.75	33.85

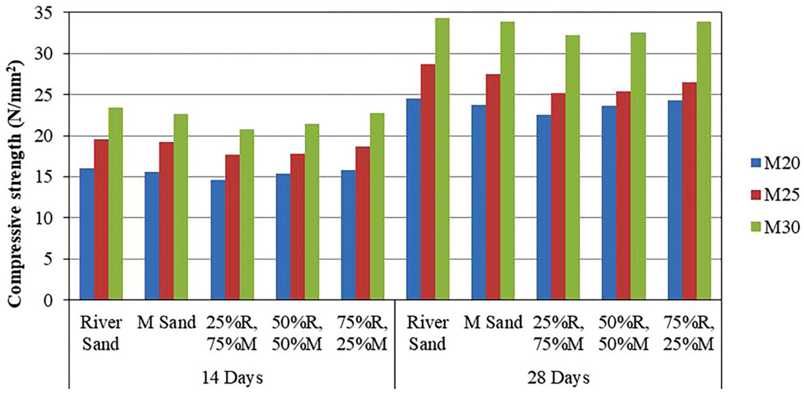

Figure 5: Compressive strength test results of 14 days and 28 days.

Figure 6: Split tensile strength test on compression testing machine.

Table 6: Split tensile strength test results (N/mm^2).

GRADE OF CONCRETE	RIVER SAND		M-SAND		25%R, 75%M		50%R, 50%M		75%R, 25%M	
	14 DAYS	28 DAYS	14 DAYS	28 DAYS	14 DAYS	28 DAYS	14 DAYS	28 DAYS	14 DAYS	28 DAYS
M20	2.15	2.77	2.10	2.67	1.90	2.55	2.05	2.60	2.10	2.65
M25	2.55	2.94	2.40	2.80	2.35	2.75	2.40	2.85	2.45	2.90
M30	2.90	3.37	2.75	3.17	2.75	3.15	2.80	3.20	2.85	3.25

compressive strength, especially when used in combination with river sand. Among the combination of M-sand and river sand, the optimal mix proportion appears to be a combination of 75% river sand and 25% M-sand. This combination consistently provides high compressive strength across all grades of concrete tested, indicating that M-sand can be utilized in concrete with the mixer of river sand. It is also observed that pure M-sand shows slightly lower compressive strength compared to river sand in all grades. However, the mix of M sand and river sand shows substantial development in strength, indicating that M-sand can be effectively utilized without compromising the concrete's strength. The compressive strength test results indicate that M-sand is a suitable and effective auxiliary for river sand in concrete mix designs for M20, M25, and M30 grades. The amalgamation of 75% river sand and 25% M-sand provides the best results in terms of compressive strength, making it an optimal choice for structural applications.

3.2. Split tensile strength

Split tensile strength is a quantity of the tensile strength of concrete, which is the ability of concrete to resist tension or being pulled apart. While concrete is robust in compression, it is relatively feeble in tension. Therefore, understanding and measuring the tensile strength of concrete is critical for confirming the durability and structural integrity of concrete structures. Split tensile strength of concrete is also an important characteristic measure of concrete. The split tensile strength test is carried out on a cylindrical concrete specimen of 150 mm in diameter and 300 mm in length. Total of 30 samples were cast for the experimental investigation. The test were performed in 2000 kN automatic compression testing machine. The cylindrical specimen is positioned horizontally between the loading surfaces of the testing equipment. The load is applied along the vertical diameter of the cylinder until failure occurs. Figure 6 shows the typical arrangement split tensile strength test in automatic compression testing machine.

$$T = \frac{2P}{\pi DL} \tag{5}$$

The tested specimen's split tensile strength are calculated using the Eq.5 where T is the split tensile strength, P is the maximum applied load, D is the diameter of the cylinder, and L is the length of the cylinder.

Table 6 presents the findings of split tensile strength test. The table shows that the high split tensile strength is observed in the concrete samples cast with river sand. Pure M-sand shows slightly lower split tensile strength compared to river sand in all grades. However, the result of M-sand is comparable with the results of concrete samples cast with river sand and the mix of M-sand and river sand shows significant improvement in strength, indicating that M-sand can be effectively used without compromising the concrete's tensile strength. The optimal mix proportion appears to be a combination of 25% river sand and 75% M-sand. This combination consistently provides high split tensile strength across all grades of concrete tested, indicating that M-sand can enhance concrete properties. The split tensile strength test results indicate that M-sand is a suitable and effective replacement for river sand in concrete mix designs for M20, M25, and M30 grades. The combination of 75% river sand and 25% M-sand provides the best results among the mixture of river sand and M-sand in split tensile strength, making it an optimal choice for structural applications where tensile strength is a critical factor.

4. DURABILITY PROPERTIES

Durability is one of the most critical aspects of concrete performance, as it determines the longevity and resilience of concrete structures under various environmental conditions. Durability testing of concrete assesses its ability to withstand chemical attack, weathering action, abrasion, and other deteriorative processes while preserving its desired engineering characteristics. Durability properties of concrete can be assessed in various experiments including, Water Permeability Test, Rapid Chloride Penetration Test (RCPT), Alkalinity test, Impact resistance test, Freeze-Thaw Resistance Test, Sulfate Attack Resistance Test, Alkali-Silica Reaction (ASR) Test, Abrasion Resistance Test, Carbonation Depth Test, Electrical Resistivity Test etc. Among three tests were performed in the present study. They are RCPT, Alkalinity test and Impact resistance test.

4.1. Rapid Chloride Penetration Test (RCPT)

The Rapid Chloride Penetration Test (RCPT) is a widely useful method to evaluate the resistance of concrete to chloride ion penetration. Chloride ions are harmful to reinforced concrete structures because they can promote corrosion of the embedded steel reinforcement, drastically decreasing the structure's durability and longevity. The RCPT provides a quantitative measure of a concrete sample's ability to resist chloride ion penetration, making it an essential part of durability testing. The principal objective of the RCPT is to evaluate the electrical charge passed through a concrete sample over a specified period, which correlates with the permeability of chloride ions to concrete. The test results indicate the concrete's ability to resist chloride dispersion and, by extension, its susceptibility to reinforcement corrosion. The RCPT measures the total charge passed through a concrete sample when subjected to a voltage difference between two solutions: one containing sodium chloride (NaCl) and the other containing sodium hydroxide (NaOH). A higher charge passed indicates higher permeability to chloride ions, suggesting lower resistance to chloride penetration.

Concrete specimens are formed using conventional moulds with a diameter of 150 mm and a height of 300 mm. After hardening, the concrete samples are cut into 50 mm thick specimens using a circular saw cutting machine. The side surfaces of the discs are coated with epoxy to prevent current leakage, leaving only the top and bottom surfaces exposed. The concrete discs are vacuum-saturated in water to ensure they are fully permeated with water before testing. The test cell consists of two compartments, each containing a solution. One compartment is filled with a 3.0% NaCl solution, and the other with a 0.3 N NaOH solution. The concrete disc is placed between the two compartments. Electrodes are placed in each solution compartment, and a voltage of 60V DC is applied across the sample. The positive e terminal is connected to NaOH solution and the negative terminal is connected is connected to NaCl solution. The LCD display shows the current passing through the modules in milliamps. Figure 7 shows the typical arrangement of RCPT test in the RCPT apparatus. The test runs for 6 hours. The current passing through the sample is recorded at regular intervals. To compute the total charge passed (in coulombs), integrate the current over a 6-hour period.

The average current flowing through one cell (I) is computed using the Eq.6

$$I = 900 \times \left(I_0 + I_{360}\right) + 2\left(I_{cum}\right) \quad (6)$$

Figure 7: RCPT test process in RCPT apparatus.

Where

$$I_{cum} = I_{30} + I_{60} + I_{120} + I_{150} + I_{180} + I_{210} + I_{240} + I_{270} + I_{300} + I_{330}$$

I_0 = *Initial measurement of* coulombs *reading in mA*
I_{30} = *Measurement of* coulombs *at* 30 *minutes in mA*
I_{60} = *Measurement of* coulombs *at* 60 *minutes in mA*
I_{90} = *Measurement of* coulombs *at* 90 *minutes in mA*
I_{120} = *Measurement of* coulombs *at* 120 *minutes in mA*
I_{180} = *Measurement of* coulombs *at* 180 *minutes in mA*
I_{210} = *Measurement of* coulombs *at* 210 *minutes in mA*
I_{240} = *Measurement of* coulombs *at* 240 *minutes in mA*
I_{270} = *Measurement of* coulombs *at* 270 *minutes in mA*
I_{300} = *Measurement of* coulombs *at* 300 *minutes in mA*
I_{330} = *Measurement of* coulombs *at* 330 *minutes in mA*
I_{360} = *Final measurement of coulombs at* 360 *minutes in mA*

The total charge transmitted through the concrete sample is used to classify the chloride ion penetrability of concrete according to Table 7. The table provides the guidelines for RCPT results and their vulnerability according to the widely accepted standard of ASTM C1202. According to this table, the chloride ion penetrability is negligible when the average current flow is less than 100 and high when the average current flow is more than 4000 C.

Table 8 shows RCPT test results in coulombs. It is observed that all values for chloride ion penetrability are below 1000 coulombs, which falls within the "Very Low" category according to the RCPT classification Table 5. As well, the results indicate that M-Sand provides comparable, and in some cases slightly improved, resistance to chloride ion penetration related to river sand. The mixture of 75% river sand and 25% M-sand consistently shows comparatively good performance across all grades. And, for each grade, the chloride ion penetrability values are very close to each other, indicating that the type of sand (river sand or M-sand) and their combinations have a minimal effect on the chloride ion penetrability within the "Very Low" range.

M-sand is as effective as river sand in providing resistance to chloride ion penetration. This is evident from the similar RCPT values across all grades of concrete tested. Given the "Very Low" chloride ion penetrability values, all tested concrete mixes are highly durable in environments exposed to chloride ions. This makes

Table 7: RCPT rating as per ASTM C1202.

CHARGE PASSED (COULOMBS)	CHLORIDE ION PENETRABILITY
< 100	Negligible
100-1000	Very Low
1000-2000	Low
2000-4000	Moderate
> 4000	High

Table 8: RCPT test results in coulombs.

GRADE OF CONCRETE	CHLORIDE ION PENETRABILITY IN CONCRETE MADE WITH				
	RIVER SAND	M-SAND	25%R, 75%M	50%M, 50%R	75%R, 25%M
M20	479.55	477.07	472.5	480.9	479.6
M25	476.80	478.99	477.2	480.2	479.9
M30	476.71	473.39	478.8	477.8	478.9

Table 9: Alkalinity test results.

GRADE OF CONCRETE	ALKALINITY OF CONCRETE MADE WITH				
	RIVER SAND	M SAND	25%R, 75%M	50%R, 50%M	75%R, 25%M
M20	11.46	11.37	11.43	11.34	11.58
M25	11.51	11.39	11.42	11.34	11.53
M30	11.49	11.39	11.43	11.32	11.55

them suitable for use in structures like bridges, marine environments, and other areas where chloride-induced corrosion is a concern. The RCPT results demonstrate that M-sand is a viable alternative to river sand in concrete mix designs, providing comparable and sometimes superior resistance to chloride ion penetration. These findings buttress the use of M-sand in concrete production, contributing to sustainable construction practices and enhancing the durability of concrete structures. The RCPT results indicate that concrete made with M-Sand exhibits very low chloride ion penetrability, comparable to that of river sand. This low penetrability suggests that M-Sand concrete can effectively resist chloride-induced corrosion, making it suitable for infrastructure in marine environments or areas exposed to deicing salts, where chloride ingress is a significant concern.

4.2. Alkalinity test

The alkalinity of concrete is an important property that influences its durability, particularly with respect to the protection of embedded steel reinforcement from corrosion. The alkalinity test of concrete measures the pH level, which reflects the concentration of hydroxide ions in the pore solution of the concrete. High alkalinity helps in maintaining a passive oxide layer on the steel, preventing corrosion. High alkalinity also helps to lower the carbonation process. Concrete with high alkalinity is more resistant to acidic attacks. Low pH environments can lead to deterioration of concrete structures. High alkalinity can serve as an indicator of the quality and performance of concrete, especially in terms of its long-term durability. Regular testing and monitoring of concrete's alkalinity help in identifying potential durability issues, guiding the design and maintenance of concrete structures to prevent premature deterioration and failure. Understanding the factors affecting alkalinity and implementing measures to maintain high alkalinity levels are essential for enhancing the performance and sustainability of concrete constructions.

After 28 days of curing, sample grade specimens were removed from the curing tank. The specimens were dried at 105°C for 24 hours. The dried specimens were cooled to room temperature. The cooled specimens are crushed separating the mortar from the concrete. The mortar was then ground into a powder. The powdered mortar was sieved with a 150µ sieve. 10gm of sieved mortar powder was diluted in 50ml distilled water and well mixed. The pH metre was then put in the solution, and its pH was measured. This provides a direct measure of the concrete's alkalinity. Table 9 shows the alkalinity test results.

As per ASTM D 4262, the recommended alkalinity values of concrete samples are in the range of 9 to 12. It is observed from the table that all measured pH values are above 11, indicating high alkalinity across all concrete mixes, which is generally good for protecting steel reinforcement from corrosion. For M20, M25, and M30 grades, the alkalinity of concrete made with river sand is slightly higher than that made with M-sand. However, the difference in alkalinity between river sand and M-sand is minimal, suggesting that both materials produce concrete with high alkalinity. Results insist that M-sand is a suitable alternative to river sand in terms of maintaining high alkalinity in concrete. The slight difference in pH values indicates that M-sand can effectively contribute to high alkalinity, which is essential for protecting steel reinforcement from corrosion. The mix proportion of 75% river sand and 25% M-sand consistently shows the highest alkalinity. This suggests that this combination is optimal for enhancing the alkalinity of concrete. In addition, high alkalinity values (above 11) across all mixes indicate that the concrete is well-protected against carbonation and chloride-induced corrosion, contributing to the durability and longevity of the structures. And, the slight variations in alkalinity between different mix proportions suggest that changing the proportion of river sand and M-sand has a minimal impact on the overall alkalinity of the concrete. This indicates flexibility in using M-sand to replace river sand without significantly affecting the alkalinity. These findings support the use of M-sand as a viable and effective substitute to river sand in concrete production, helping to sustainable and durable construction practices. The high alkalinity levels observed in the M-Sand concrete mixes, comparable to those of river sand, are crucial for protecting steel reinforcement from corrosion. This ensures that structures built with M-Sand will maintain their structural integrity over time, especially in environments where the concrete is exposed to carbonation or other factors that could reduce its pH.

4.3. Impact resistance test

The Repeated Impact Resistance Test, commonly known as the ACI Drop Weight Test (ACI544), is a method used to evaluate the impact resistance of concrete. Impact resistance refers to concrete's capacity to absorb unexpected pressures or shocks without sustaining severe damage. This property is crucial for structures subjected to dynamic loads, such as those caused by machinery, vehicles, or seismic activity. The American Concrete Institute (ACI) provides guidelines for this test to ensure consistency and reliability in assessing the impact resistance of concrete. The primary objective of the Repeated Impact Test is to measure the number of strikes required to produce initial visible cracking and ultimate failure in concrete specimens. This helps in understanding the concrete's toughness and ability to withstand repeated dynamic loads.

Figure 8 shows the typical impact resistance test in impact resistance test apparatus. Cylindrical concrete specimens of diameter of 150 mm and height of 50 mm were taken for this impact test. Specimens were cured under standard conditions to achieve the desired strength before testing. Figure shows the impact resistance test in the impact resistance test apparatus. The test apparatus consists of a base plate, a steel ball, and a drop hammer. The specimen is put on the base plate, with the steel ball on top of it. The drop hammer is aligned vertically above the steel ball. The drop hammer weighing 4.54 kg is dropped from a height of 457 mm (18 inches) onto the steel ball. The impact from the drop hammer is transferred to the concrete specimen through the steel ball, simulating a dynamic load. The number of strikes required to cause the first visible crack in the specimen is recorded. The test continues, and the number of additional blows required to cause ultimate failure (defined as the specimen breaking into several pieces or showing significant fragmentation) is recorded. The total number of blows for the first fracture and eventual failure is used to determine the concrete's impact resistance. Absorbed impact energy can be calculated by the Eq.7 and Eq.8.

$$IE_1 = N_1.mgh \tag{7}$$

$$IE_2 = N_2.mgh \tag{8}$$

Where N_1 is the number of blows till the first crack, N_2 is the total number of blows till the ultimate strength or final crack, m is the mass of the hammer = 4.54 kg, g is the acceleration due to gravity = 9.81 m/s^2 and h is the dropped height of the hammer = 457 mm.

This test is importance since the test provides a measure of the concrete's toughness, which is its ability to absorb energy and resist fracture under repeated impacts. And it allows for the comparison of different concrete mixes, including the effects of various aggregates, admixtures, and reinforcement (such as fibers) on impact resistance. In addition, it helps in assessing the quality and durability of concrete, ensuring it meets the required standards for structures exposed to dynamic loads. Moreover, it provides valuable data for optimizing

Figure 8: Typical impact resistance test in impact resistance test apparatus.

Table 10: Impact test results.

GRADE OF CONCRETE	TYPE OF SAND	N_1 (blows)	N_2 (blows)	IE_1 kNm	IE_2 kNm	DUCTILITY INDEX (IE_2/IE_1)
M20	River Sand	6	8	0.1221	0.1628	1.33
M25		10	14	0.2035	0.2850	1.40
M30		16	20	0.3257	0.4071	1.25
M20	M-sand	5	7	0.1018	0.1425	1.40
M25		9	12	0.1832	0.2442	1.33
M30		14	17	0.2850	0.3460	1.21
M20	25%R, 75%M	4	5	0.0814	0.1018	1.25
M25		7	9	0.1425	0.1832	1.29
M30		12	14	0.2442	0.2850	1.17
M20	50%R, 50%M	5	7	0.1018	0.1425	1.40
M25		9	11	0.1832	0.2239	1.22
M30		13	16	0.2646	0.3257	1.23
M20	75%R, 25%M	6	8	0.1221	0.1628	1.33
M25		9	11	0.1832	0.2239	1.22
M30		14	18	0.2850	0.3664	1.29
Mean		**9.266**	**11.80**	**0.1886**	**0.2402**	**1.2885**

concrete mix designs to enhance impact resistance, which is crucial for applications like industrial floors, pavements, and protective barriers.

Table 10 shows that the number of blows for the initial and final cracks increases with the grade of concrete. The pattern is observed in the absorbed impact energy too. M30 grade of concrete absorbed more energy when compared to the M20, and M25 grades of concrete. It is observed that the impact resistance values of concrete cast with M-sand are comparable with the impact resistance of concrete cast with the River sand. As well the combination of river sand and M-sand results are also equitable with the results of river sand. It reveals that M-sand can be used as a good alternative to the river sand. The mean number of strikes required to induce the first visible break is 9.266 for all samples, indicating that concrete cast with river sand and M-sand is highly impact resistant. Similarly, the mean value of number of blows to cause final crack is 11.80 indicating that he the concrete could absorb 0.052 kNm impact energy in an average after the first crack. It has been observed over river sand as well M-sand based concretes. This indicates that the concrete could observe impact energy even after the development of first cracks. This characteristic is very comparable to river sand and M-sand-based concretes.

The ductility index measures a material's capacity to experience substantial plastic deformation before breaking. It provides an indication of how well the material can absorb energy and deform without cracking. In the context of concrete, a higher ductility index suggests that the concrete can sustain more deformation under impact loads, which is a desirable property for structures subjected to dynamic loads such as earthquakes or blasts. The ductility index of the tested concrete indicates that it varies from 1.1 to 1.4 and the average ductility index of the tested concrete is 1.289. This is an evidence of high impact energy absorption of the tested concrete samples. The results indicate that M-sand is a viable alternative to river sand, providing comparable impact energy. These findings support the use of M-sand in concrete production, particularly in applications where impact resistance is demanded. The impact resistance test results further demonstrate that M-Sand can be effectively used in concrete for applications that require high impact durability, such as industrial floors, pavements, and structures subjected to dynamic loads, including those in seismic zones.

5. CONCLUSION

The study aims to investigate the suitability of M-sand as an alternate to the traditional river sand for the construction activities. The following conclusions were drawn from this investigation.

- The grading analysis revealed that both River sand and M-Sand fall within Grading Zone II as per IS 383-2002, making them medium sands suitable for concrete production. The grading curves showed a similar distribution pattern, ensuring good workability and compaction. The specific gravity of M-Sand (2.68) was slightly lower than that of River sand (2.75) but within the acceptable range for concrete aggregates. Mixtures of river sand and M-Sand also exhibited specific gravity values close to pure river sand, indicating that M-Sand can be used effectively without compromising concrete quality.
- Concrete made with M-Sand demonstrated compressive strength comparable to that made with river sand across all tested grades (M20, M25, M30). The optimal results among the combination of mixes were observed with a combination of 75% river sand and 25% M-Sand, suggesting that M-Sand can partially replace river sand without sacrificing strength. Similar trends were seen in the split tensile strength tests, where M-Sand showed slightly lower but still comparable tensile strength to river sand. Among the combination of 75% river sand and 25% M-Sand showed the highest split tensile strength, further supporting the use of M-Sand in concrete mixtures.
- In terms of durability, the Rapid Chloride Penetration Test (RCPT) indicated that M-Sand provided comparable resistance to chloride ion penetration as river sand, with all tested concrete mixes falling within the "Very Low" category for chloride ion penetrability. This indicates high durability and suitability for use in environments exposed to chloride ions. The alkalinity test showed that both river sand and M-Sand mixes maintained high alkalinity levels (above pH 11), which is crucial for protecting steel reinforcement from corrosion. Additionally, the impact resistance test revealed that concrete made with M-Sand had comparable impact resistance to that made with river sand, with a ductility index indicating good impact energy absorption supporting the use of M-Sand in impact-resistant applications.

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