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Inspection of the mechanical and durability behavior of concrete developed using M-sand

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Abstract
In response to the increasing pressures of urbanization on the construction industry and the subsequent rise in concrete production, which leads to the overexploitation of river sand (R-sand), this research addresses the imperative of enhancing mechanical properties while aligning with environmental considerations by choosing manufactured sand (M-sand) as a sustainable replacement for R-sand. The study began by analyzing essential parameters, including fresh densities and mechanical concrete properties, and subsequently investigated durability aspects through assessments of permeability, acid, and sulphate resistance effects in M-sand concrete mixes. Through systematic replacements of R-sand with M-sand, ranging from 0% to 100% at 25% intervals, using the widely employed M 30 grade, the research evaluated performance. Fresh properties analysis revealed that M-sand concrete exhibited lower workability but increased fresh density compared to R-sand concrete. Mechanical strength tests indicated that the incorporation of M-sand led to enhanced compressive, flexural, and tensile strength, with the fine texture and unique bonding properties of M-sand particles playing a crucial role. Permeability assessments demonstrated reduced water penetration in M-sand concrete, decreasing from 69.5 mm to 64.5 mm. This improvement was attributed to a denser concrete structure resulting from the filler effect of M-sand. Moreover, the study highlighted M-sand's 15% and 12% greater resistance against sulphate and acid exposure, respectively, further corroborated by enhanced mass retention and compressive strength in harsh chemical environments.

Keywords
M-sand, Durability aspect, Waste concrete, Acid and Sulphate attack.

1.Introduction
Growing global demand for river sand (R-sand), especially in India, is unsustainable, consuming 32-50 billion tonnes annually for concrete. This overuse threatens supply. R-sand extraction harms the environment and infrastructure. In response, M-Sand is a popular, consistent, and legal alternative. When using unwashed M-Sand, be aware of potential higher fines content, requiring more water for workability. Replacing R-sand with M-Sand enhances overall strength and performance of concrete. Manufacturing sand (M-Sand) also outperforms R-sand in terms of strength, with particle shape and texture less influential than stone powder (SP) and clay content. Choosing the right application can optimize M-Sand performance in concrete.

In the realm of construction materials, the amalgamation of aggregates bound by cementitious paste has granted concrete unparalleled versatility, strength, and durability. This compels concrete to emerge as the paramount choice for construction endeavors [1, 2]. The expanding urban landscapes worldwide have triggered a surge in construction activities, consequently driving the demand for cement to unprecedented heights. Projections made in 2016 forecasted a robust annual growth rate of 5.2%, catapulting the global cement market to an astounding 51.7 billion tons [3, 4]. This escalating construction fervor has escalated the necessity for sand, a pivotal component in concrete manufacturing [5]. The conventional choice of natural R-sand as a fine aggregate has encountered challenges due to its depleting availability and soaring costs [6, 7]. In response, manufactured sand has gained prominence as a promising alternative. Characterized by its finer particles that adeptly fill microscopic concrete pores,

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M-sand not only enhances concrete strength but also offers the benefits of lower costs, reduced pollution, and ready availability [8–11]. The application of M-sand has grown exponentially, finding utility in road projects, buildings, and even the production of bricks and tiles [12, 13]. However, the existing body of research on M-sand's integration into concrete production has grappled with certain limitations. Previous studies, such as those conducted by Karthik et al. (2017) [9] and Shen et al. (2016) [12], have examined aspects like M-sand's shape, texture, and morphology, but a comprehensive understanding of its influence on concrete properties remains somewhat elusive.

Questions surrounding the implications of these disparities on concrete's workability and strength continue to persist [14]. Driven by the escalating demand for construction materials, especially sand, and the potential advantages offered by M-sand, this study seeks to bridge the knowledge gaps surrounding its impact on concrete properties. The primary objectives of this paper encompass a comprehensive exploration of the effects of M-sand on diverse concrete characteristics, the elucidation of its benefits and challenges in concrete formulation, and the provision of insights that can guide practitioners and researchers in optimizing concrete production using M-sand. Through this study, a significant contribution to the field is envisaged. It will offer a holistic assessment of M-Sand's influence on concrete, encompassing mechanical properties, workability, setting time, and even ecological implications linked to reduced sand extraction.

The paper's organizational structure ensures a systematic approach to addressing the research objectives, with Section 1 covering the introduction, Section 2 delving into the literature review, Section 3 detailing the methodology, Sections 4 and 5 presenting the results and discussion, and concluding in Section 6. By adhering to this structure, the study aims to offer a comprehensive understanding of the impact of M-sand on concrete properties. This, in turn, provides valuable insights to the construction industry and the broader scientific community.

2.Literature review

Yang et al. (2023) [15] have experimentally evaluated the M-sand concrete by analysing the impact on carbonation performance with the incorporation of stone dust in the mix. The sole purpose for this study was to enhance the durability of mix as well as to encourage the M-sand utilisation. In their experimental work they assessed the depth of carbonation at varied content of stone dust along with the analysis of pore solution pH and rebar's half-cell potential. Scanning electron microscopy (SEM) analysis reveals that a 7% stone dust content yields the best results, with minimum carbonation depth, maximum rebar half-cell potential, and reduced porosity.

Zhao et al. (2023) [16] study explores an ecological approach to concrete production by utilizing a mix of coarse M-sand with the incorporation of super-fine R-sand to reduce carbon emissions in infrastructure construction. The pumpability and mechanical properties of the mixed-sand concrete were assessed, and comparative performance has been represented with the conventional concrete. The study highlights the potential for further enhancements in flowability and tensile strength.

Zheng et al. (2023) [17] examines the high-strength M-sand concrete for the durability characteristics, the impact of high fines content was assessed for the mix prepared with the incorporation of granite and limestone M-sand. The study finds that a fines content of 10% yields the smallest carbonation depth and effectively improves chloride and sulphate impermeability. The durability of the concrete is best when the fines content is controlled within 5% to 15%. However, excessive fines can hinder cement hydration and compromise concrete durability.

Verma (2022) [18] explores geopolymer concrete as an alternative to conventional concrete, with a focus on replacing r-sand with stone dust. The results show improved mechanical properties, including higher compressive, splitting tensile, and flexural strengths, as well as slightly higher elastic modulus and ultrasonic pulse velocity in the stone-dust specimens. Rebound strength follows a similar trend to compressive strength.

Liu et al. (2023) [19] have made experimental assessment on nano silica (NS) modified M-sand concrete comparative properties analysis was made on mixes which were cured with standard and steam methods. NS has a similar positive effect on both methods, mitigating loss of later strength as well as the impermeability caused by steam curing. NS also enhances early strength gaining along with this corrosion resistance coefficient in steam-cured concrete also achieved. The study attributes these improvements to increased consumption of calcium hydroxide and enhanced hydration product generation, repairing micro-defects caused by steam curing.

Liu et al. (2023) [20] introduces economical and environmentally friendly reactive powder concrete (RPC) using M-sand as fine aggregate. The M-sand RPC mix has been assessed under different curing methods viz. Natural curing method (NC), as well as with the standard curing (SC) and combination of the natural and heat curing method. Microstructure of the mix and the mechanical characteristics of the mix were interrelated with the microstructure analysis under different curing conditions. The findings support the practical engineering application of RPC, with M-sand RPC meeting performance standards for engineering components under all curing methods. Notably, combined natural and heat curing method enhances early strength through increased calcium silicate hydrate (C-S-H) production and reduced internal porosity.

Duan et al. (2022) [21] analyses M-sand concrete for steam curing temperature and duration and assessed the impact on compressive strength of mix. It aims to optimize both early and late strength development. Findings reveal that a 6-hour steam curing at 40°C leads to limited hydration product coverage and lower early-stage strength due to unreacted cement. Prolonged high-temperature steam curing (>48 hours) results in uneven hydration product distribution and decreased later-stage strength. Recommended constant temperature stage durations for 40°C, 50°C, and 60°C are 6.2–31 hours, 4–19 hours, and 2.7–13 hours, respectively. The study also refines the maturity function to better estimate concrete strength, considering thermal damage during high-temperature steam curing.

Altuki et al. (2022) [22] investigates sustainable M-sand as potential fine aggregates for concrete. Aggregate imaging system, uncompacted voids content and microscopic inspection were performed for the process of quantification of shape properties of M-sand as well as the natural sand. Concrete mixtures with varying M-sand proportions are evaluated for workability. Correlations between shape measurements and concrete performance are established, suggesting adjustments to the tarantula curve for enhanced accuracy.

Han et al. (2022) [23] explores the impact of M-sand on water reducer adsorption, commonly used to enhance concrete fluidity. Different grade strength levels (30 MPa to 80 MPa) of M-sand concrete are investigated using basic and optimized water reducer dosages. Tests cover slump, slump loss, along with the analysis of uniaxial compression, and pore content. Findings reveal that optimized water reducer dosage boosts fluidity, peak stress, and elastic modulus, while reducing slump loss, peak strain, and pore content. Applying the lemaitre damage mechanism, concrete damage is categorized into initial and load-induced damage. Higher fluidity reduces initial damage and influences stress-strain relationships. Increased initial damage alters pore structure, decreasing concrete strength and modulus.

Ren et al. (2022) [24] examines the challenges conventional concrete rheological predictions by considering irregular aggregate particle shapes. Predictions for MS concrete rheological properties are established using a multi-level biphase model. The proposed models exhibit strong accuracy and robustness in accounting for various particle shapes and size distributions of MS and coarse aggregate mixtures. These predictions elucidate the impact of particle shapes on rheological properties through relative paste and mortar film thicknesses. This innovative approach forms the basis for optimizing concrete proportions with irregular aggregate, aligning with desired rheological criteria.

Zhang et al. (2022) [25] examines the viability of replacing r-sand with M-sand in concrete structures, the mixes were analysed under atmospheric acidification conditions. Various laboratory tests were performed which includes accelerated carbonation and dry-wet circling for sulphate attack. The comparative analysis of surface damage, mass change, compressive strength, and carbonization depth reveals that sulphate attack causes severe concrete surface damage, while carbonization leads to mild damage. In accelerated carbonation, early-stage compressive strength of M-sand concrete outperforms r-sand concrete, though the trend reverses later. Both concretes experience gradual compressive strength decline under sulphate attack, with M-sand concrete showing a gentler decline. The presence of SP in M-sand positively influences concrete pore filling, rendering it advantageous for use in an atmospheric acidification environment.

Xu et al. (2022) [26] examines fracture parameters and the fracture process zone (FPZ) in M-sand recycled aggregate concrete (RAC) with different recycled coarse aggregate (RCA) replacement rates. Using three-point bending tests, a crack identification method (TCIM) accurately locates crack tips and

FPZ, coupled with digital image correlation (DIC) for fracture mechanism analysis. RAC's FPZ evolution is compared to M-sand natural aggregate concrete (NAC). Results reveal stable crack identification with TCIM, while RAC shows similar initial fracture toughness but reduced unstable fracture toughness and energy, indicating increased brittleness with higher RAC replacement rates. RAC's FPZ evolution involves three stages, influenced by RAC's effects on aggregation interlocking, crack growth, and damage behaviour.

Shen et al. (2022) [27] showcases a case of cleaner production for high-quality digital control manufacturing sand (DMS) and the ecological utilization of recycled SP. The DMS production system improves sand quality and recycles SP, minimizing environmental impact. DMS offers better gradation, particle shape, and adjustable SP content, simplifying its application. Concrete with DMS displays enhanced working performance (16.19% increase), average strength (7.1% increase), and excellent chloride ion resistance. DMS usage reduces cement content and achieves zero waste discharge, yielding notable economic and ecological benefits.

Mane et al. (2021) [28] investigates the mounting electronic waste (E-waste) poses a nationwide challenge with limited recycling (12.5%). To address this, the study explores incorporating E-waste into concrete, reducing natural resource use and landfill impact. E-waste, mainly from printed circuit boards, substitutes fine and coarse aggregates. The research investigates replacing M-sand with E-waste at different percentages (0%, 10%, 20%, 30%, 40%) in M30 grade concrete. Optimal results occur with 20% E-sand substitution, enhancing strength, chloride permeability, and microstructure compared to traditional concrete.

Pranavan and Srinivasan (2021) [29] studies the concrete consumption has surged, becoming a fundamental construction material, composed of cement, fine aggregate, coarse aggregate, and water. Meeting this demand requires ample fine aggregate, traditionally sourced from R-sand and M-sand. Escalating usage of these resources, however, coupled with governmental restrictions on r-sand mining, has prompted the adoption of M-sand as a substitute. Despite untreated sea sand's salt content, it's being considered as an alternative. This study assesses the mechanical properties of complete M-sand, complete sea sand, and a 50% blend M-sand with sea sand. The aim is to balance environmental resource preservation and sustainable development. Experimental results reveal that sea sand-based concrete exhibits unexpectedly improved strength compared to M-sand-based concrete.

Surendar et al. (2021) [30] investigates the mechanical and durability properties of RAC compared to conventional NAC. Seven concrete mixes were tested, varying the percentage of RCA replacement: 0%, 10%, 15%, 20%, 25%, 50%, and 75%. Cube compressive strength, cylinder split tensile strength at 7 and 28 days, and water absorption were measured. Optimal replacement of recycled aggregate can enhance concrete's mechanical and durability properties, mitigating environmental impacts associated with recycled aggregate.

Fournari and Ioannou (2019) [31] studied the correlations between the properties of crushed fine aggregates. Standardized tests such as soundness, water absorption and relative density were performed on crushed fine aggregates. Non- standardized tests were conducted on crushed fine aggregate to study the different mineralogical composition. It was concluded that the mineralogical composition of crushed aggregate affects the physical mechanical properties of fine aggregate.

Pawar et al. (2014) [32] analysed the base utilization of sand content in concrete. In this exploration work it was reasoned that M-sand could be a suitable substitute for R-sand. The trial examination assessed the impact of rate substitution of R-sand by M-sand sand with 40%, 60%, 70%, 80% and 100% according to the standard for an outlined concrete extent of 1:1.5:3 R-sand. It was contemplated and demonstrated that M-sand have better bonding and good gradation which is comparatively less in R-sand.

Jadhava and Kulkarni (2012) [33] investigated the impact of M-sand on workability and compressive strength. The test examination demonstrated that there was an increment in compressive strength by 5.7% when the R-sand was supplanted by M-sand. For complete supplanting of R-sand by M-sand the compressive strength is enhanced by 7.03%, which is observed to be the maximum. It was additionally reasoned that the R-sand can be entirely supplanted by M-sand however, the concrete mix becomes tough with the increase in the proportion of M-sand.

Joseph et al. (2013) [34] studied the impact of combined high alumina cement, silica fume and M-sand in concrete. This examination was completed to look at the impact of different substitution levels of cement by high alumina cement and silica fume and the fractional supplanting of fine aggregate with M-sand for M25 and M30 grade concrete. In this examination, it was demonstrated that the strength developed at a speedier rate after hardening. Following three days of curing the compressive strength was observed to be 28.8 MPa and 26.51 MPa for the cube and cylindrical specimen. It was discovered that 20% of compressive strength is enhanced by utilizing M-sand for R-sand in concrete.
M-sand is in very much use due to the scarcity of R-sand. It is produced by granite stone after the process of pulverization and later it is graded as per the required proportion. Compared to the R-sand, it found to be more cost efficient as well as its working characteristics is also nice, along with this it is found with less impurities. The traditional R-sand utilisation is considered to be harming the eco-system of river due to excessive quarrying; hence M-sand is also proved to be eco-friendly. Concrete produced with M-sand is stronger than routine materials used in concrete [35].

In summary, the studies showcased a wide array of advancements in concrete technology, focusing on durability, sustainability, and novel material utilization. However, there are still gaps to address. Further research is needed to comprehensively understand the long-term performance of alternative materials like M-sand and its reactivity with cement paste in real-world conditions. Additionally, the interactions between irregular aggregate shapes and concrete rheology warrant more investigation. Bridging these gaps will pave the way for more effective and sustainable concrete solutions in the future.

3.Materials and methods

3.1Raw ingredient

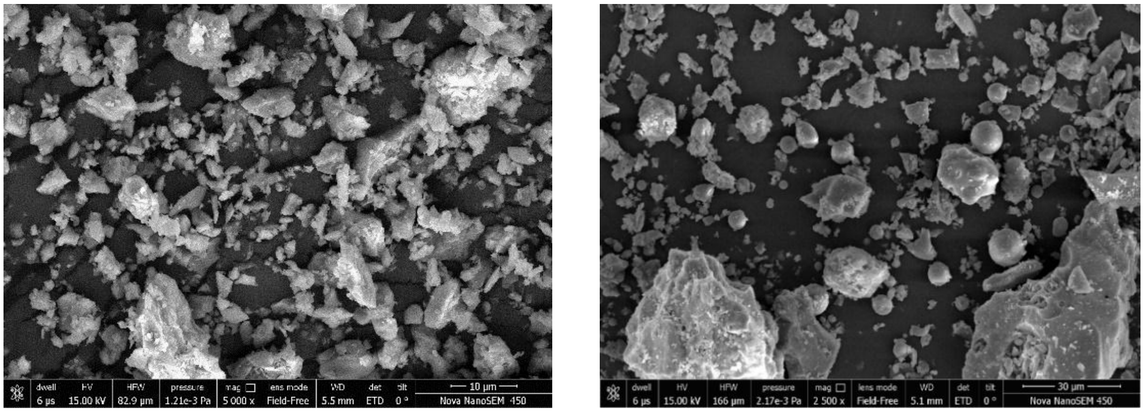
Portland pozzolana cement (PPC) compatible to IS 383 [36], is utilised in the experimental analysis that is having specific gravity as 3.1. As per the recommendation of IS 383:2016, the R-sand conforming zone II were utilised with the values as 1685 kg/m3 and 2.62 for the density and specific gravity respectively. Whereas, the values observed for utilised M-sand are as 1710 kg/m3 and 2.61 for the density and specific gravity respectively. *Table 1* and *2* shows the physical properties of raw materials and aggregates. The utilised M-sand also indorse the grading of zone-II. One of the recognized concrete R-sand are used as fine aggregates. Since there is a problem for R-sand everywhere there is a need of the hour to find alternate or substitute materials for it. It was found that the study on M-sand as fine aggregates is limited and hence this motivated to study and examine on the effect of M-sand in concrete. The research aims to assess the feasibility of using M-sand as a fine aggregate and study its properties as an alternative in concrete production. Hence, the scope of this work includes the determination of properties of both fresh and hardened concrete produced with M-sand. *Figure 1* illustrated SEM images of cement, R-sand, M-sand and cement. From the below SEM images, it is clearly visible that the R-sand has a smooth texture and better shape whereas M-sand has a rough texture and an angular shape. An energy dispersive X-ray spectroscope (EDS) test conducted and identified the constituents, characterization of materials used. *Figure 2* shows the EDS analysis of cement, R-sand, M-sand and cement. It was found that the cement was having major composition of calcium, silica, alumina and magnesium.

Table 1 Physical properties of raw material

Property	**Cement**	**Fine aggregate**	**Coarse aggregate (10 mm)**	**Coarse aggregate (20 mm)**
Specific Gravity	3.12	2.61	2.71	2.69
Water Absorption (%)	-	1	0.34	0.32
Fineness Modulus	-	2.23	4.98	7.22

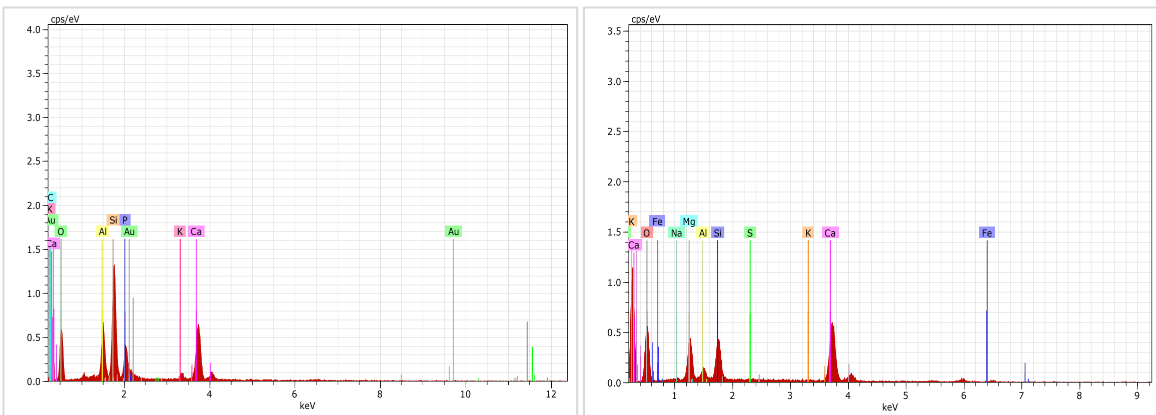
Table 2 Properties of aggregates

Parameter	**Aggregate**	**R-Sand**	**M-Sand**
Size in mm	12.50	4.75	4.75
Water Absorption (%)	0.34	1	1
Specific gravity	2.73	2.62	2.61



(a) (b)

Figure 1 SEM images of a) R-sand b) M-sand



(a) (b)

Figure 2 EDX of a) R-sand b) M-sand

3.2Mix proportioning

In this study M30 grade is decided to inspect the influence of water type for mixing and curing of concrete. *Table 3* shows the mixing details for different mixes with type of water used for mixing of concrete. Dosage of admixture were adjusted to achieve required slump of 100-110 mm as water influences the slump value of mixes. The analysis of the mechanical as well as the durability characteristics have been performed for the different levels of replacement varying from 0 to 100 percent for M-sand by R-sand at an interval of 25 percent, and the replacements are denoted from 0 to 4 respectively as per the compositions.

Table 3 Mix Proportion for the Various M-sand percentage of concrete

M-Sand (%)	Mix ID	Cement	M-Sand	R-Sand	Coarse aggregate		Water	Admixture
					20 mm	10 mm		
0	M0	392	-	613	691	455	177	3.14
25	M1	392	153	460	691	455	177	3.14
50	M2	392	307	307	691	455	177	3.14
75	M3	392	460	153	691	455	177	3.14
100	M4	392	613	-	691	455	177	3.14

3.3Testing program

For compressive strength test, in accordance with IS 516:1959 [37] the samples were prepared with 100 mm3 size and the testing for the samples were performed after 28 and 90 days at a uniform loading of 140 $kg/cm^2/min$ on compressive testing machine. Similarly, split tensile strength of concrete samples size 300mm height and 150 dimeter is evaluated after 28 days of curing. Flexural strength of concrete without and with M-sand were studied. Four-point loading arrangement was followed for this test. In line with american society for testing and materials (ASTM) C78-84 provisions, prism of size 100 × 100 × 500 mm was used. The loading was done gradually until fracture when the failure load and point of fracture were recorded. Rate of loading was 29.43 N/sec (180 kg/min). Pure bending theory is applicable in this test since all fracture failure taken place within the middle third portion of specimens tested.

The ecological components concerning to structures are key factor that affects the durability of the concrete. Concrete structures are found with water ingress due to permeability that occurs due to the water penetration through capillaries under straining. The resistance to the penetration is assessed using this method. In accordance to the ASTM C1202-10 [38], the durability of the specimen is investigated by the electrical test method. The criterion values are depicted in the *Table 3*. This is done to find the capability of concrete to resist penetration. This test is an electrical test that is used to estimate the durability of concrete as per ASTM C1202-10. There are 2 reservoirs in the instrument, out of which one is filled with the 3% NaCl solution and another one is filled with 0.3M NaOH. The size of the testing sample is kept as 5 cm thick and diameter is as 10 cm. Concrete sample is applied with the constant voltage for a time period of 6 hours and later the Coulombs are assessed by marking down the current passing through the sample. The classification as well as the record of chloride permeability is assessed using the results of the test. The water absorption investigation is carried to find out the voids that entrap the water, higher number of voids tend to raise the water absorption of the concrete specimen, and it will lead to the deterioration of the concrete. ASTM C642-06 [39] specification were followed for the investigation of water absorption, initially the weight of saturated sample for surface dry condition were noted, later the sample is kept in the constant temperature oven for period of 24 hours and the weight is noted for it, the reduction in the weight is depicted in percentage for the value of water absorption.

The carbonation is the process that takes place when the cement reacts with the CO_2 present in the surrounding. Also, the acidic reactions take place when it comes in contact with salts and the acid rains. The disintegration of the concrete takes place when it left for the direct exposure to these conditions. Generally, the presence of sewerage or the industrial SO_2, makes the concrete susceptible to the sulphuric acid attack, which leads to the corrosion. The reaction of gypsum presents in the concrete with the sulphuric acid tend to decompose the concrete integrity and it leads to the reduction in the compressive strength.

4.Results

4.1Fresh properties

The fresh density as well as workability of various fresh concrete mixtures was assessed to investigate effect of M-sand over concrete and same has been depicted in *Figure 3*. *Figure 4* shows the bulk and apparent densities of concrete. It reveals that the M-sand concrete mixes give lower workability than R-sand concrete.

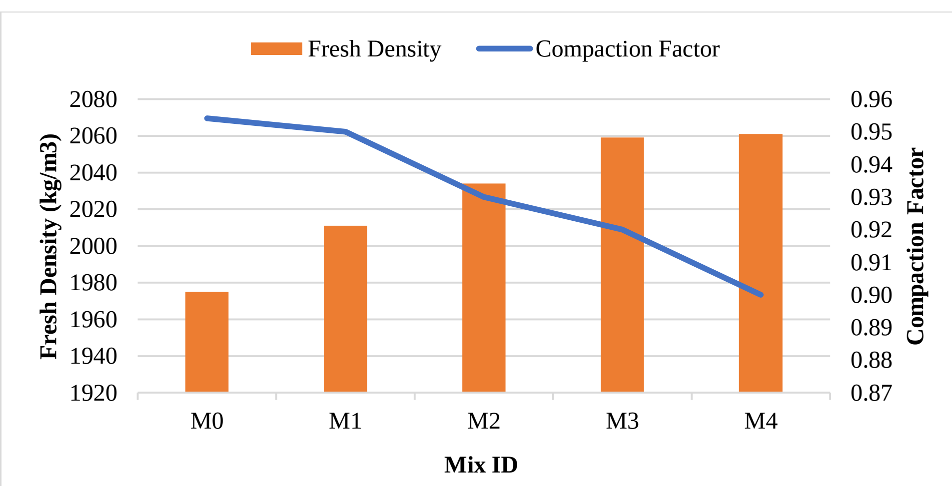


Figure 3 Fresh density and compaction factor for M-sand concrete

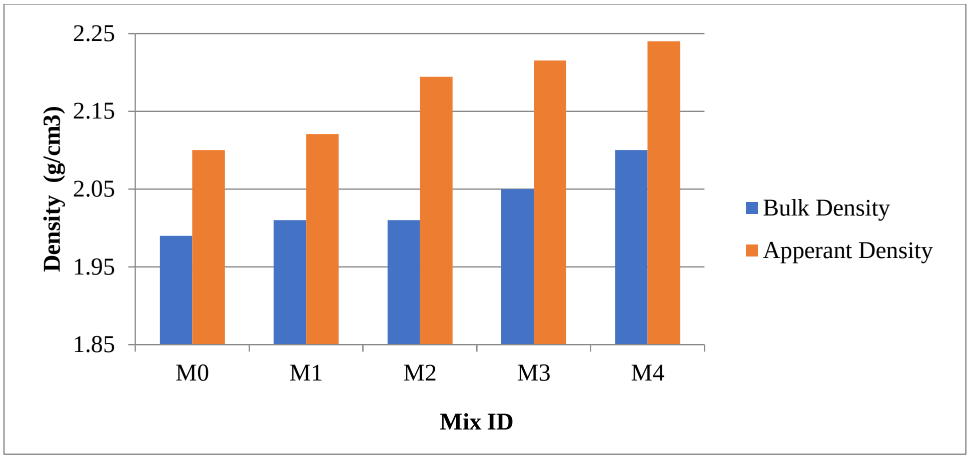


Figure 4 Bulk and apparent density for M-sand concrete

4.2Mechanical strength

The specimens of grade M30 were tested which were prepared for the substitution level of M-sand varying from 0% to 100% at an interval of 25%, the results of the tests are depicted in *Figure 5*.

Figure 6 depicts the observation of split tensile and flexural strength teat results for 28 days cured samples. It has been seen from the *Figure 6* that increment is observed in both the parameters as the substitution of M-sand is increased.

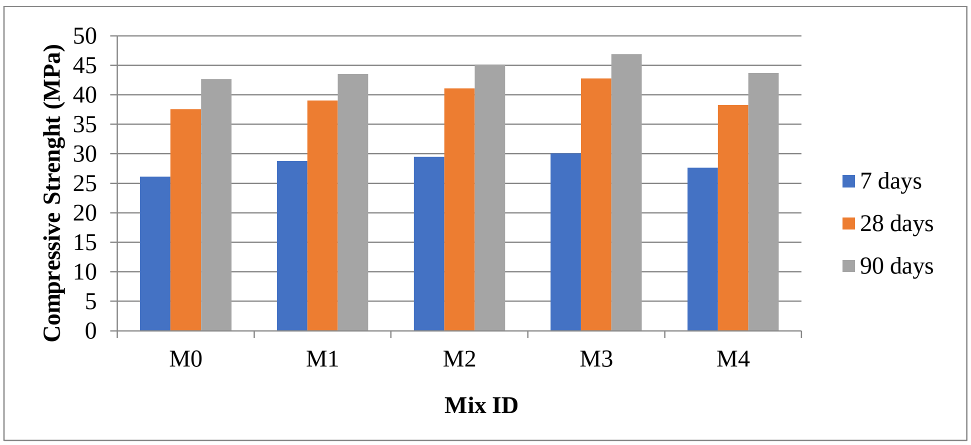


Figure 5 Compressive strength results for M-sand concrete

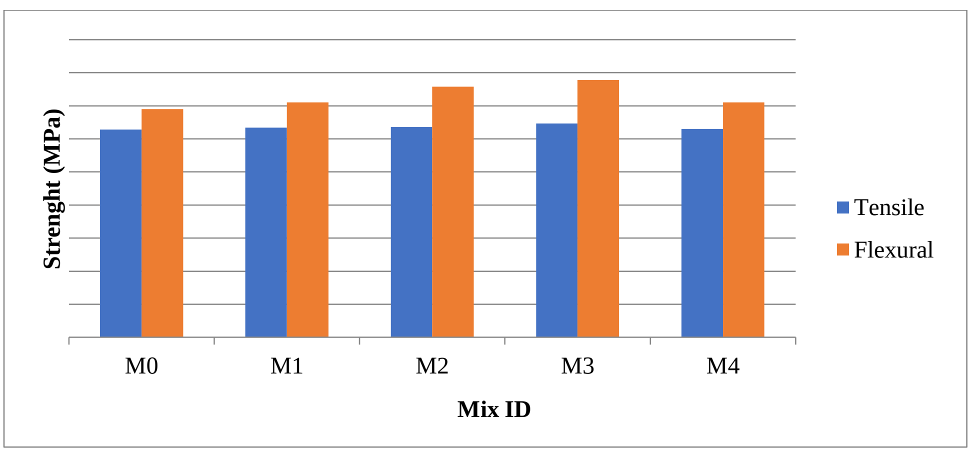


Figure 6 Split tensile and flexural strength results for M-sand concrete

4.3Permeability and porosity

Permeability for different mixes was investigated for better understanding of durability properties concrete. Durability is highly affected by the water permeability. Water penetration depths were assessed to determine the permeability for samples under standard specified conditions. *Figure 7* depicts the water permeability for various M-sand specimens.

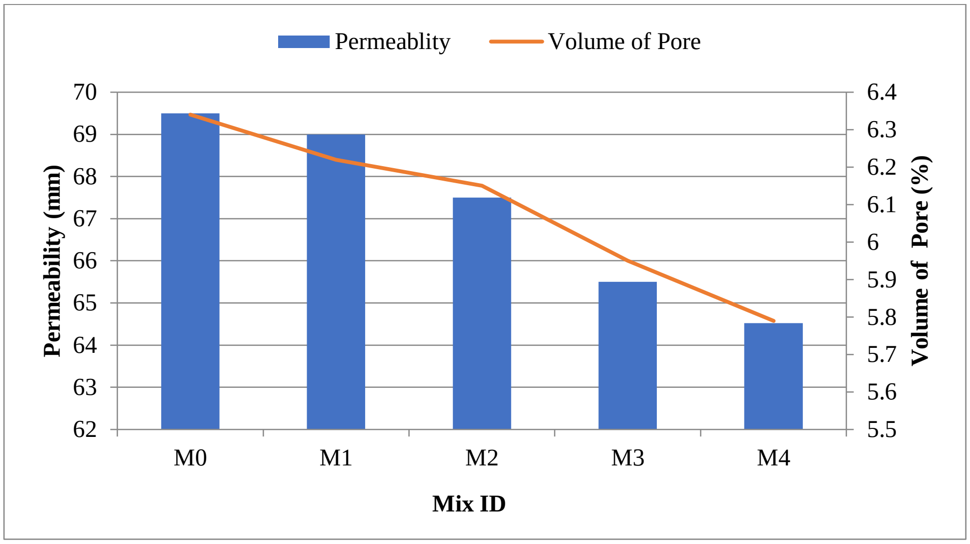


Figure 7 Permeability and volume of voids results for M-sand concrete

4.4Acid and sulphate resistance test

Figure 8 depicts the result of the samples cured in sulphate for a period of 7 and 28 days. For the period of 7 days testing mix M0 have depicted highest weight gain, whereas, the mixes prepared with M-sand substitution have depicted reduction as the level of substitution increased. *Figure 9* depicts results of concrete samples exposed to acid for compressive strength. *Figures 10* and *11* depicts the result of change in weight the samples exposed to magnesium sulphate and sulphuric acid for a period of 7 and 28 days.

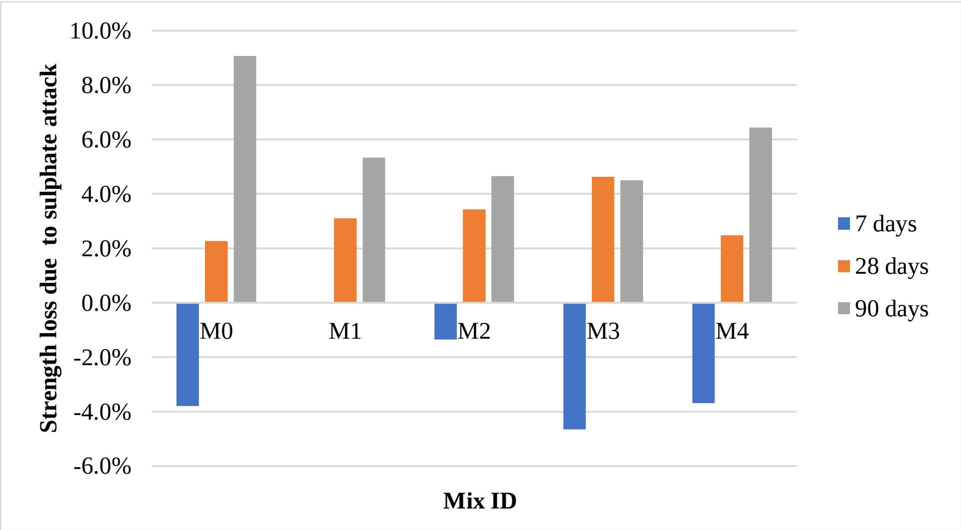


Figure 8 Strength loss due to sulphate attack results for M-sand concrete

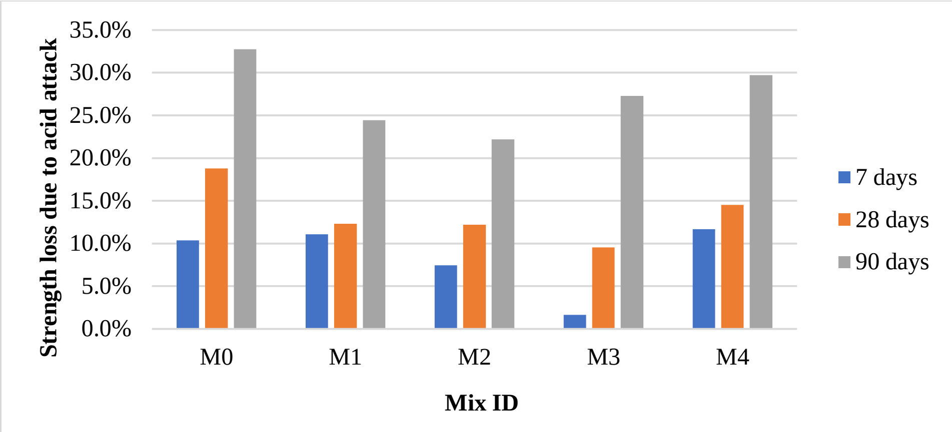


Figure 9 Strength loss due to acid attack results for M-sand concrete

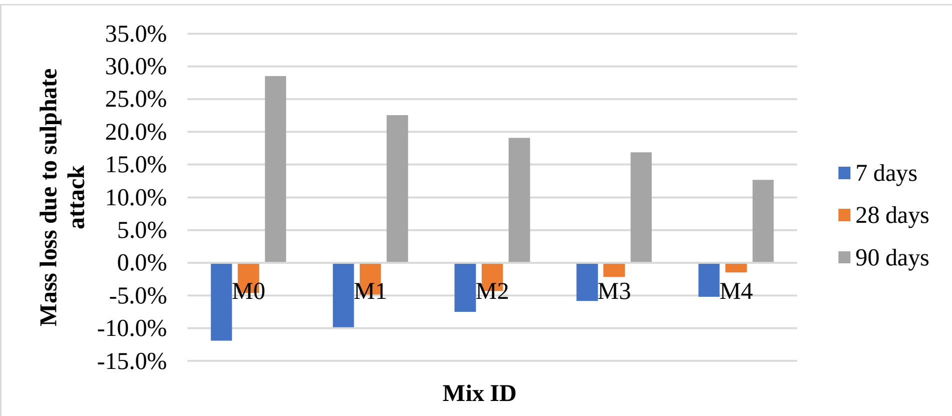


Figure 10 Mass loss due to sulphate attack results for M-sand concrete

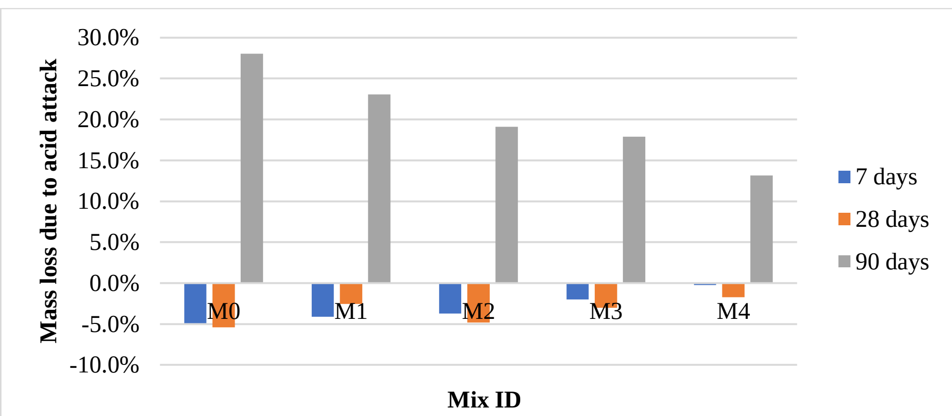


Figure 11 Mass loss due to acid attack results for M-sand concrete

5.Discussion

5.1Fresh Properties

It reveals that the M-sand concrete mixes give lower workability than R-sand concrete. The workability of concrete not much affected by using M sand as value given by the code. The density of concrete shows that by using M- sand the fresh density of concrete was increased due to finer particle induced in concrete [40]. The apparent density and fresh density relate that by using M-sand as compared to R-sand the densification of concrete might be increased.

5.2Mechanical strength

The findings have depicted that mix M3 has the highest compressive strength which have 75% M-sand substitution level, the archived strength is 12% more compared to the control mix M0, further substitution have reduced the strength of mixes, whereas, the reduction is found to be lower compared to the control mix. The compressive strength of the samples was taken after 7, 28, and 90 days of curing. It can be observed that compressive strength of M3 reached to 45 N/mm² at 90 days curing. Interestingly, all specimens containing M-sand display higher compressive strength than the control concrete. This phenomenon can be attributed to the finer texture and sharper edges inherent in M-sand, which contribute to its superior integration within the concrete matrix.

It has been seen from the *Figures 5* and *6* that increment is observed in both the parameters as the substitution of M-sand is increased. Variation in the flexural strength were observed as varying in between the range of 8 to 12 percent of compressive strength. Comparing to the control mix, M3 mix have depicted 8% rise for the split tensile strength and 12% rise for the flexural strength. The underlying reasons for these strength improvements can be attributed to two factors: the filler effect and the unique bonding properties of M-sand. The irregular and acute shape of M-sand particles contributes to enhanced bonding within the concrete structure. This, coupled with the filler effect, leads to improved strength parameters. Beyond the identified level of substitution, however, a decrease in strength occurs due to the formation of voids within the concrete matrix [41, 42].

5.3Permeability and porosity

Permeability for different mixes was investigated for better understanding of durability properties concrete. Durability is highly affected by the water permeability. Water penetration depths were assessed to determine the permeability for samples under standard specified conditions. It has been observed from the results that as the substitution of M-sand raised from 0 to 100 percent, comparing to control mix the decrement in the water penetration were observed as 69.5, 69, 67.5, 65.5 and 64.5 mm in M-sand specimens.

This effect can be attributed to the alteration in void ratio within the concrete matrix due to the addition of M-sand. Void ratio refers to the ratio of the volume of void spaces (pores or gaps) to the total volume of the material. The incorporation of M-sand, which possesses fine particles and sharp edges, leads to a more compact arrangement of particles in the concrete mixture. As a result, the void spaces between the particles are reduced, thereby diminishing the pathways through which water can permeate the concrete.

In simpler terms, the irregular and fine nature of M-sand particles fills the gaps between the larger aggregates in the concrete mixture, resulting in a denser structure. This densification restricts the movement of water, preventing it from easily seeping into the concrete. Consequently, as the substitution of M-sand increases, the reduction in void spaces contributes to the observed improvement in water penetration resistance. The data presented in the study, particularly reference [43], supports these conclusions regarding the impact of M-sand on reducing water permeability in concrete.

5.4 Acid and sulphate resistance test

The research results illustrate intriguing trends in the weight change and compressive strength of different concrete mixes, particularly when exposed to acid and sulphate environments.

In the case of Mix M4, the most pronounced weight reduction of 3.17% is observed after 28 days of exposure to acid. This reduction, however, is notably lower for the mixes with M-sand substitution levels up to 75%. *Figure 9* displays the outcomes of samples exposed to magnesium sulphate for both 7 and 28 days. The results showcase that as the substitution levels of M-sand increase, the change in weight for the mixes becomes less significant over the specified time frames. The M3 mix shows the highest weight gain, with values of 0.09% and 0.32% for 7 and 28 days respectively. Similarly, the M4 mix records values of 0.03% and 0.19% for the same periods.

The formation of various by-products resulting from the reaction between concrete components and acids has a substantial influence on the variations in compressive strength. The M4 mix demonstrates a 3.04% increase in compressive strength when compared to the M0 mix after 7 days of acid exposure. This is in contrast to the 7.21% alteration observed in the M0 mix. The presence of M-sand introduces a filler effect, which accounts for the comparatively lower increase in compressive strength. The reduced void ratio in the M4 mix contributes to higher compressive strength due to minimized void spaces. The limited formation of ettringite within these reduced pores can lead to greater strength gains. Notably, the control sample exhibits a significant strength increment at the 7-day mark when subjected to sulphate curing in comparison to specimens with M-sand substitution. However, as the exposure period extends beyond 7 days, the decline in strength is most pronounced in the control specimen. Conversely, samples prepared with M-sand substitution experience a lesser decrease in strength over time.

The variations in weight and compressive strength can be attributed to the intricate interplay of factors. The reduced weight change and improved strength retention in M-sand-substituted mixes can be attributed to the denser structure resulting from the presence of fine M-sand particles. These particles fill voids between larger aggregates, rendering the mix more resistant to the penetration of acids and sulphate ions. This increased resistance limits the formation of by-products that degrade the concrete matrix, leading to better preservation of compressive strength.

The outcome highlights the advantageous impact of M-sand in enhancing the durability and strength retention of concrete in harsh chemical environments. The findings discussed in references [44–46] substantiate these observations, reinforcing the understanding that the unique attributes of M-sand contribute to mitigating weight loss and strength reduction in concrete under acid and sulphate exposure.

5.5Limitation of study

Certainly, here's the limitations inferred from the studies:

- Short-Term Focus: The studies evaluated concrete properties over 7, 28, and 90 days, potentially missing long-term durability concerns.
- Lab vs. Real-world: The controlled lab conditions might not fully replicate real-world scenarios, where concrete faces diverse environmental factors.
- Sample Size: Lack of information on sample size and replication raises questions about statistical significance.
- Mix Variability: Findings might not apply universally, as concrete mix designs and requirements can differ.
- External Factors: Concrete properties are influenced by curing methods, mixing, and interactions with additives.
- Long-Term Durability: Effects of M-sand on concrete microstructure and long-term durability weren't extensively explored.
- Practical Scaling: Challenges in large-scale construction, like mixing and placement, weren't addressed.
- Comparative Analysis: Lack of comparison with other substitutes limits a holistic understanding.

While positive aspects of M-sand in concrete were highlighted, these limitations underline the need for comprehensive, practical, and diverse studies to fully understand its benefits and drawbacks.

A complete list of abbreviations is shown in *Appendix I.*

6.Conclusion and future work

This study aimed to comprehensively investigate the impact of incorporating M-sand on concrete performance. The assessment encompassed various aspects, including fresh properties, density, mechanical strength, and durability, particularly focusing on acid and sulphate resistance in M-sand replaced concrete.

The key findings of this research are as follows:

- Enhanced Concrete Densification: The use of M-sand led to an increase in the apparent density and fresh density of concrete compared to R-sand. This indicates that M-sand contributed to a denser concrete matrix, likely due to the finer particle size and smoother texture of M-sand particles.
- Improved Compressive Strength: Across all specimens containing M-sand, the compressive strength exhibited consistent improvement over the control concrete. This enhancement can be attributed to the finer nature and sharper edges of M-sand particles, which promote better integration and bonding within the concrete matrix.
- Increased Flexural and Tensile Strength: Notably, M-sand mixes demonstrated improved flexural and tensile strength when compared to conventional concrete. This strength enhancement can be attributed to the unique characteristics of M-sand, including its irregular shape and fine texture, which facilitate stronger interlocking within the concrete structure.
- Reduced Water Penetration: The samples containing M-sand displayed decreased water penetration, suggesting enhanced resistance to moisture ingress. This reduction could be attributed to the reduced void ratio within the concrete matrix, resulting from the filler effect of M-sand particles. The finer particles effectively occupy the spaces between larger aggregates,

creating a more compact structure that impedes water movement.

- Enhanced Sulphate Resistance: M-sand concrete exhibited notable improvements in sulphate resistivity compared to normal concrete. The strength of M-sand concrete increased by approximately 3%, and its mass resistance improved by approximately 15% against sulphate exposure. This enhanced resistance is likely due to the refined particle size and unique bonding properties of M-sand, which mitigates the degradation caused by sulphate ions.
- Improved Acid Resistance: Similarly, M-sand concrete demonstrated enhanced resistance to acid environments. The compressive strength of M-sand concrete increased by around 3%, and its mass resistance improved by about 14% compared to normal concrete when exposed to acids. The improved performance can be attributed to the increased density and reduced void spaces within the concrete matrix, minimizing the adverse effects of acid exposure.

This research emphasizes the multifaceted advantages of incorporating M-sand in concrete. The findings highlight the potential for M-sand to enhance concrete properties, including density, mechanical strength, and durability against both sulphate and acid exposure. These results underscore the potential of M-sand as a valuable ingredient in concrete mixes, with the capacity to positively impact various performance metrics critical to concrete's long-term functionality in diverse environments.

This work can be extended to include microstructural analysis to validate the anticipated outcomes of the mix performance. Additionally, studying long-term durability, the effects of mix-design variation, and the incorporation of nano-materials in mix preparation can be undertaken to enhance the overall properties of the mix.

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Conflicts of interest
The authors have no conflicts of interest to declare.

Author’s contribution statement
Ashish Mathur: Concept and formulation, method of analysis, writing – original draft, analysis and interpretation of results. **Dr. R.C. Chhipa**: Supervision, final correction, investigation on challenges and draft manuscript preparation. **Dr. Mala Mathur**: Writing – revision draft, analysis and interpretation of results.

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Appendix I

S. No.	Abbreviation	Description
1	ASTM	American Society for Testing and Materials
2	CSH/C-S-H	Calcium Silicate Hydrate
3	DMS	Digital Control Manufacturing Sand
4	DIC	Digital Image Correlation
5	EDS	Energy Dispersive X-ray Spectroscope
6	E-waste	Electronic Waste
7	FPZ	Fracture Process Zone
8	IS	Indian Standard
9	M-sand	Manufacturing Sand
10	NAC	Natural Aggregate Concrete
11	NC	Natural Curing Method
12	NS	Nano Silica
13	PPC	Portland Pozzolana Cement
14	RAC	Recycled Aggregate Concrete
15	RCA	Recycled Coarse Aggregate
16	RPC	Reactive Powder Concrete
17	R-sand	River Sand
18	SC	Standard Curing
19	SEM	Scanning Electron Microscopy
20	SP	Stone Powder
21	TCIM	Three-Point Bending Tests, a Crack Identification Method