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Impact of Polyester Recron 3s Fiber on Fly Ash-based Portland Pozzolana Cement Mortars at Various Total Dissolved Solids Levels

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Abstract

This research investigates the effect of total dissolved solids (TDS) concentration on the properties of cement mortar, including setting time, flowability, compressive strength, water absorption, and permeability, with a constant addition of 0.5% Recron fiber. TDS levels were categorized as <500 ppm, 500–1500 ppm, 1500–2500 ppm, and >2500 ppm to reflect different water qualities. Results highlight the significant role of chloride ions in TDS, accelerating cement hydration and reducing setting time, particularly at 1500–2500 ppm. However, excessive TDS (>2500 ppm) causes flocculation, slightly delaying the setting process. Moderate TDS levels (500–1500 ppm) improved early compressive strength by filling cement pores, but strength declined beyond this range. Flowability remained consistent across all samples (105–115% flow), regardless of fiber inclusion or water quality variations. Higher TDS levels slightly reduced water absorption due to pore filling, while improving impermeability. A minor increase in permeability at elevated TDS concentrations suggests complex interactions affecting mortar durability. Additionally, Fourier Transform Infrared Spectroscopy (FTIR) and Scanning Electron Microscopy (SEM) analysis revealed changes in silicate structures influencing durability. This research is novel in simultaneously investigating TDS concentration and fiber reinforcement, offering practical recommendations for coastal construction.

Keywords

cement mortar, total dissolved solids, Recron fiber, Portland Pozzolana Cement, Fourier Transform Infrared Spectroscopy, mortar properties

1 Introduction

Mortar, a bonding agent used in construction, is typically fabricated by interweaving cementitious material (cement or lime), fine aggregate (sand, surkhi, etc.), and water [1]. They are utilized to cohere building blocks, such as bricks and stones; and have been used since the dawn of civilization [2]. Portland cement, hydrated lime, and sand are its ternary elements. Portland cement offers mixture strength while lime provides flexibility and elasticity [3]. Mortars are commonly employed for masonry work, plastering, and pointing. This binding material affords structural stability [4] and is designed to hold up against aggressive conditions, such as deterioration, across its lifespan [5]. The research studies the role of Recron 3s fibers, a variety of polyester fibers, contrary to polypropylene fibers in cement mortar to enhance its compressive strength and crack resistance during the hydration process [6]. Polypropylene is primarily adopted for concrete flooring in the basement where heavy trafficking occurs, and the concrete's abrasion caused by the creation of heavy friction during vehicle movement can be avoided [7]. Recent studies have indicated that the full strength and crack resistance of Recron fiber-reinforced brickwork and plasterwork outperform other materials with appending cement mortar [8–10]. This investigation strives to comprehend the mechanisms of the bonds developed between mortar and brick and concludes that the brick–mortar

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bond is essentially mechanical [11–13]. The core objective of the study is to counter the failures taking place in conventional mortar and to alter and amplify the compressive strength along with the durability and bond strength [14]. Hence, masonry structures are built in a way to ensure safety and are cost-effective [15]. According to the earlier findings on mortar and its strength in masonry, mortar is resilient in compressive strength and conversely fragile in tension [16]. Consequently, the structure is more prone to frequent fissures due to minor disruption, still, enriching polyester in mortar improves the compressive strength, tensile strength, the service of masonry work, and prevents fracture formation [17].

Islam et al. [18] noted the repercussions of seawater, cement–slag mix proportions, water–binder ratios, and curing periods on mortar strength. The findings revealed that a 70:30 cement-slag ratio and a 0.46 water-binder ratio offer enhanced compressive strength and endurance to strength deterioration across the curing conditions and ages [19]. Çomak [19] investigated the impact of physical, mechanical, and microstructural properties of cement mortar due to the influence of varying pH of water added to the mortar with NaOH. The optimum results were obtained at pH 12 where the compressive strength and workability were improved for the mortars made with pH-adjusted water [20, 21]. Porosity analysis was also executed after 28 days. Mohanraj and Vidhya [22] investigated the effect of seawater and undersalted sea sand on Portland cement mortar, with a focus on hydration, mechanical properties, and phase changes. Sea sand salts speed up early hydration and strength, yet a drop was noted in their long-term strength due to their physical properties [23]. Chloride, sulfate, and magnesium ions from seawater and sea sand alter the hydration products, resulting in the formation of more Friedel's/Kuzel's salts and ettringite and increasing the Si/Ca ratio of C-S-H. The use of seawater and sea sand in concrete extends a self-sustaining solution for overcoming natural resource deficit [24]. The demand for freshwater in concrete production conflicts with the predicted water shortages reported by Yiğiter et al. [25]. Using seawater and byproducts such as fly ash and slag also facilitates sustainability by reducing CO_2 emissions. Sheng et al. [26] reported the reactivity and applicability of a low-impact mortar made with seawater and sea sand from the Eastern Seas of China. The physicochemical–mechanical behaviors were evaluated via Unconfined Compression Tests, Energy Dispersive Spectroscopy, X-ray Diffraction, and Scanning Electron Microscopy analyses. The results demonstrated that C-S-H and C-A-S-H formation enhanced the uniaxial compression strength and reduced the porosity [27]. Novel models have shown that salts crystallize and withstand damage in critical environments. Qin et al. [28] examined the impacts of coral powder content and seawater salinity on cement mortar properties and compressive strength tests. The results signify that coral powder accelerates hydration and improves mortar strength, whereas salt reduces stiffness and enhances coral powder aggregation [29]. These findings can direct the optimization of the mechanical properties of coral sand–seawater mortars for structural stability. Li et al. [30] examined OPC hydration in seawater and distilled water, focusing on phase evolution, hydration kinetics, and microstructure. Seawater accelerates C3S hydration, promotes Friedel's salt formation, and stabilizes ettringite, affecting mortar strength [31]. Qu et al. [32] investigated sulfate attacks on Portland cement mortars immersed in seawater and groundwater. Chlorides in seawater form protective compounds such as Friedel's salt, enhancing durability [33, 34]. Brucite layers in seawater offer better protection against solution ingress than those in groundwater. Zhang et al. [35] reported the use of seawater, coral sand, and sea sand in alkali-activated mortars and cement mortars. Seawater and coral sand enhance early-age strength and reduce drying shrinkage by facilitating C-S-H gel formation. Coral sand affects the workability and setting time, whereas sea sand adversely affects the compressive strength due to the presence of free water. Li et al. [36] investigated the thermal properties of alkali-activated slag materials using seawater and sea sand at elevated temperatures up to 1000 °C. It analyzes mechanical degradation in paste and concrete due to thermal gradients and phase changes, emphasizing challenges with aggregate–paste thermal compatibility [37, 38]. Benli et al. [39] noted the mechanical and durability properties of self-compacting mortars (SCMs) incorporating silica fume (SF) and fly ash (FA) immersed in seawater and magnesium sulfate solutions. According to Choi et al. [40], the impact of seawater exposure on cement mortar involves the incorporation of silica fume, metakaolin, or glass powder at various replacement levels. It assesses mechanical, durability, and microstructural properties and has beneficial effects on short-term flexural strength and durability, particularly with metakaolin, but has limited long-term durability enhancements [41].

The objective of the study is to design a stable and affordable mix design for mortar incorporating Recron 3s fiber, determine the optimal percentage of Recron fiber to enhance the bond strength, durability, and compressive strength, and comprehend the effects of varying the amount of mixing water (ppm), mixture on the performance of the Recron fiber-containing mortar mixture. Despite extensive research on fiber-reinforced mortars, a significant gap exists in understanding the precise impact of Polyester Recron Fiber on the mechanical properties of cement mortar, especially under varying water content conditions. This research addresses the gap by providing a comprehensive analysis of both the flowability and compressive strength of mortars with and without Recron fiber. The novelty of the study lies in its systematic approach to evaluating the performance of fiber-reinforced mortars with different water content ranges, revealing that the inclusion of Recron fiber at a constant 0.5% significantly enhances the mechanical properties, regardless of the TDS range. These findings showcase the strength and effectiveness of Recron fiber reinforcement, presenting a viable strategy for improving the durability and mechanical performance of cementitious materials in construction.

2 Materials and methodology

In this study, PPC cement, as specified in IS 1489-1 [42], was used for the mortar sample. The PPC is a Portland Pozzolana cement with 15–35% Fly Ash pozzolanic material [43]. The characteristic compressive strength of the cement was 33 N/mm^2 at 28 days [44]. The fine aggregates, which pass through a 4.75 mm sieve and are retained on a 0.075 mm sieve used in the mortar to proffer bulk [45]. Polycarboxylic ether was employed for the mortar, which is also a water-reducing plasticizer [46]. The admixture was IWP - Integral waterproofing. The receiver fiber used for the research has the attributes of a triangular shape cut length of 12 mm, and an effective diameter of 0.2–0.4 mm, whose Young's modulus surpasses 4000 MPa [47]. The mortar mix design involves opting for raw materials in optimal proportions to procure the intended properties of mortar both in fresh and hardened states for specific applications. For the mixing method, hand mixing was designated considering its effectiveness for limited scope projects and quantities, using a designed mix of 1:3 (Cement: Fine Aggregate) + 0.5% Recron fiber by weight of cement fused with various TDS levels of water (Fig. 1). The properties of the fine aggregate, coarse aggregate, Recron fiber and water are depicted in Tables 1–3. Mortar cubes of 70 mm size were cast and tested for compressive strength at 7, 14, and 28 days [48, 49]. Specimen preparation and

Fig. 1 Mixing of cement mortar with Recron fibers

Table 1 Properties of cement and fine aggregate

S.No.	Parameter	Cement	FA
1	Setting time (minutes)		
	Initial	36	-
	Final	588	-
2	Fineness (m^2/kg)	321	-
3	Normal consistency (%)	29.6	-
4	Bulk density (kg/m^3)	-	1804
5	Specific gravity	-	2.64
6	Bulking of sand (%)	-	24
7	Water absorption (%)		1.4

Table 2 Physical and chemical properties of Recron 3s fiber

S.No.	Parameter	Results
1	Polymer (polyethylene terephthalate)	>87%
2	Additives (titanium dioxide, optical brighteners)	<0.5%
3	Spin finish	<0.5%
4	Self-ignition temperature	515 °C
5	Decomposition temperature	>300 °C
6	Color	White
7	Appearance	Short-cut staple fiber
8	Melting point	240 °C–260 °C

Table 3 Properties of water

S.No.	Parameter	Results
1	Sulphates as SO_4, mg/L	29
2	Acidity	1.59
3	Alkalinity	11.9
4	pH value	6.75
5	Organic solids, mg/L	78.0
6	Inorganic solids, mg/L	842.0
8	Suspended solids, mg/L	<1.0

curing were adopted as per IS 9013 [50]. Adopts cement mortar mixtures of ratio 1:3 (C: FA) with a *w/c* ratio of 0.6 and 0.5% Recron fiber constant throughout the experiment. Three mortar cubes were cast for each proportion and tested at 7, 14, and 28 days, using water with varying TDS levels (<500, 500–1500, 1500–2500, and >2500 ppm) and the sample was cured with clean potable water. The salt water used in the study was prepared in the laboratory by dissolving measured quantities of salt in distilled water to achieve various TDS levels. TDS levels were precisely adjusted by dissolving measured amounts of NaCl, $CaCl_2$, and $MgSO_4$ in distilled water, simulating natural water sources. Final concentrations were confirmed using a TDS meter before use in mortar preparation. Table 4 presents the specimen details, each containing 0.50% fiber and varying concentrations of total dissolved solids (TDS) in the mixing water.

Conventional cubes without fiber and fiber-containing cubes were prepared for each water ppm category. The cube molds were cleaned, oiled, and bolted before the mortar was poured, which was blended on a clean RCC floor by hand. The cement, sand, and/or stone dust were mixed dry first, then water was added, and the mixture was thoroughly blended. The mortar was placed into molds in three compact layers, de-molded after 24 hours, and cured in a tank for 7, 14, and 28 days before testing on a universal testing machine.

3 Experimental study

3.1 Flowability test on cement mortar

The flowability test is conducted to measure the workability of cement mortar. In this test, a standard mortar mix is placed on a flow table in the form of a conical heap. The flow table is then dropped from a specific height, usually 25 drops in 15 seconds. The diameter of the spread of the mortar is measured after the drops. The flowability is calculated as a percentage based on the change in the diameter of the mortar. This test provides an understanding of the workability and ease of handling of the mortar during the mixing and application stages, which is crucial for ensuring uniformity and reducing segregation in construction.

Table 4 Specimen details

S.No.	Designation	% of fiber	TDS level (in ppm)	*w/c* ratio
1	CM 1	0.50%	< 500	0.6
2	CM 2	0.50%	500 ppm–1500 ppm	0.6
3	CM 3	0.50%	1500 ppm–2500 ppm	0.6
4	CM 4	0.50%	> 2500 ppm	0.6

3.2 Setting time test on cement

The setting time test determines the initial and final setting times of cement paste. A Vicat apparatus is used for this test. A standard cement paste is prepared by mixing cement with a specified amount of water. The paste is then placed in the Vicat mold, and a needle is used to monitor the penetration of the paste. The initial setting time is recorded when the needle can only penetrate the paste to a depth of 5–7 mm, indicating the commencement of hardening. The final setting time is when the needle no longer penetrates the paste, marking the complete hardening of the cement. This test helps us understand the working time and hardening process of cement under various conditions.

3.3 Compressive strength test on cement mortar

The compressive strength test is performed to evaluate the ability of cement mortar to withstand axial loads. The compressive strength is calculated by dividing the maximum load at failure by the cross-sectional area of the cube. This test provides insight into the mechanical strength of cement mortar at different stages of curing.

3.4 Water absorption test on cement mortar

The water absorption test assesses the ability of hardened cement mortar to absorb water. Cement mortar cubes are prepared and cured for 28 days. After curing, the cubes are dried in an oven at 105 °C for 24 hours to remove any moisture and weighed to get the dry weight (W_1). The dried cubes are then immersed in water for 24 hours to allow them to absorb water. After the immersion period, the cubes are weighed again to get the saturated weight (W_2). The water absorption percentage is calculated as the ratio of the weight of water absorbed to the dry weight. This test indicates the porosity of the mortar and its resistance to water ingress, which is essential for durability in moisture-prone environments.

3.5 Water permeability test on cement mortar

The water permeability test measures the rate at which water penetrates through cement mortar under pressure. In this test, cylindrical cement mortar specimens are placed in a water permeability apparatus where water pressure is applied to the surface of the sample. The pressure is maintained for a specified duration, typically 72 hours, and the volume of water passing through the specimen is recorded. The permeability is calculated by measuring the volume of water and the time taken for it to permeate through the specimen. This test provides information about the water-tightness of the mortar and its ability to resist water penetration, a critical factor for structures exposed to high levels of moisture or aggressive environments.

3.6 Flexural strength test on cement mortar

The flexural strength test is conducted to assess the tensile strength of cement mortar. Cement mortar prisms (40 mm × 40 mm × 160 mm) are prepared and cured for 28 days. After curing, the prisms are placed in a flexural testing machine, and a load is applied at the center of the specimen until failure occurs. The maximum load at failure is recorded, and the flexural strength is calculated. This test provides insights into the behavior of cement mortar under bending forces and is particularly important for applications where the material will experience tension, such as beams and slabs.

3.7 FTIR test on cement mortar

Fourier Transform Infrared Spectroscopy (FTIR) is used to analyze the chemical composition of cement mortar. In this test, powdered samples of cured cement mortar are prepared and analyzed using an FTIR spectrometer. The spectrometer records the infrared absorption spectrum of the sample over a range of wavenumbers, typically from 4000 cm^{-1} to 400 cm^{-1}. The resulting spectra show characteristic peaks corresponding to specific chemical bonds, such as Si-O, Ca-O, and others. This test helps identify the presence of hydration products, unreacted materials, and any chemical changes within the mortar during the curing process. FTIR analysis provides valuable insights into the mortar's chemical stability and potential durability.

4 Discussion of the test results

4.1 Flowability test

During the flow table test, cement mortar samples are meticulously prepared and subjected to testing to figure out their flow values, which are indicative of the consistency and workability of the mortar. Preparing these samples involves creating mortar batches, ensuring a controlled and iterative process. The mortar is systematically poured into molds in layers, with each layer carefully compacted via a tamping rod. This compaction process is crucial for eliminating air voids within the mortar, compromising the flow measurements' uniformity and accuracy. The standard flow table test procedure specifies that the flow values for cement mortar should range between 105% and 115%. This specified range ensures that the mortar possesses the appropriate consistency for practical application, maintaining a balance between being too fluid, which could lead to segregation, and too stiff, which could make handling and placing the mortar difficult. Despite these modifications, the flow table test results indicate that neither the incorporation of fibers nor the variation in water ppm significantly affects the mortar's flowability. The mortar consistently falls within the standard flow range of 105% to 115%, ensuring it remains workable and suitable for construction use. The *w/c* ratio for all the mixtures was maintained at 0.6 to ensure consistency. The flow percentages, which indicate the workability of the mortar, are as follows: CM 1 (TDS < 500 ppm) has a flow of 110%, CM 2 (500–1500 ppm) has a flow of 109%, CM 3 (1500–2500 ppm) has a flow of 111%, and CM 4 (TDS > 2500 ppm) has a flow of 112%. These results suggest that varying TDS levels have a minor but noticeable effect on the flowability of the cement mortar. Specifically, as the TDS concentration increases, the flowability slightly improves, with the highest TDS concentration (greater than 2500 ppm) resulting in the highest flow value of 112%. The higher TDS levels can enhance the workability of the mortar, likely due to the increased ionic presence in the water, which may reduce the friction between the particles in the mixture, leading to better flow. Overall, the flowability of the mortar ranged narrowly from 109% to 112%, indicating that higher TDS levels marginally improved workability without causing significant changes. The mortar remained workable across all the tested TDS ranges. The consistency of the flow values across different mixes underscores the high level of the mortar's workability, irrespective of the added fibers and varying water quality.

4.2 Setting time of 3s fiber cement mortar

Each level signifies a distinct range of total dissolved solids (TDS) in the mixing water, simulating various water quality conditions that may be encountered in practical scenarios. This categorization allows for an elaborate investigation of the influence of properties of the cement mortar with varying water purity and mineral content. The acceleration of the setting time of cement in the presence of recurrent fibers and various total dissolved solids (TDSs) can be attributed to two primary factors. First, the presence of chloride ions as part of the TDS composition plays a significant role in accelerating the hydration reaction of cement. Chloride ions are known to enhance the hydration process by promoting the dissolution of the aluminate and silicate phases in the cement, which in turn accelerates the formation of calcium hydroxide (C-H) and calcium silicate hydrate (C-S-H), the primary products accountable for the hardening of cement paste. Second, the increase in the amount of solid particles within the mixing water due to higher TDS concentrations effectively reduces the initial spacing between the cement grains. This reduction in spacing enhances the contact between the grains, smoothing more immediate and efficient interactions during the hydration process. The increased contact between the cement grains means that the hydration products can form more quickly, leading to a quicker setting time for the cement paste. Empirical data confirm these findings (Fig. 2). For example, a control sample with TDS concentrations ranging from 1500 to 2500 ppm had approximately 30 minutes as an initial setting time. Significant variations in the initial setting time were noted when the TDS concentration was modified. Specifically, for cement paste containing water with TDS concentrations less than 500 ppm, the initial setting time was observed as 80 minutes. This relatively longer setting time can be attributed to the lower concentration of chloride ions and fewer solid particles, resulting in slower hydration reactions and less immediate contact between cement grains. As the TDS concentration increased to between 500 and 1500 ppm, the initial setting time decreased to 60 minutes. This reduction in setting time indicates the beginning of the beneficial effects of chloride ions and additional solid particles on the hydration process and cement-grain interaction. For TDS concentrations of 1500–2500 ppm, the initial setting time was approximately 30 minutes, demonstrating an optimal balance where the acceleration effects are maximized. Remarkably, at TDS concentrations exceeding 2500 ppm, the initial setting time slightly increased to 45 minutes. This slight increase may be due to an overabundance of solid particles, which could lead to a phenomenon known as flocculation. In flocculation, excessive solid particles cause the cement grains to aggregate into larger clusters, potentially hindering optimal contact and delaying the hydration process slightly compared with the optimal TDS range. Overall, the acceleration of the setting time of cement in the presence of TDS is influenced primarily by the chloride ions accelerating the hydration reaction and the increased contact between cement grains due to the increased concentration of solid particles. The observed variations in initial setting times with varied TDS concentrations reflect the delicate

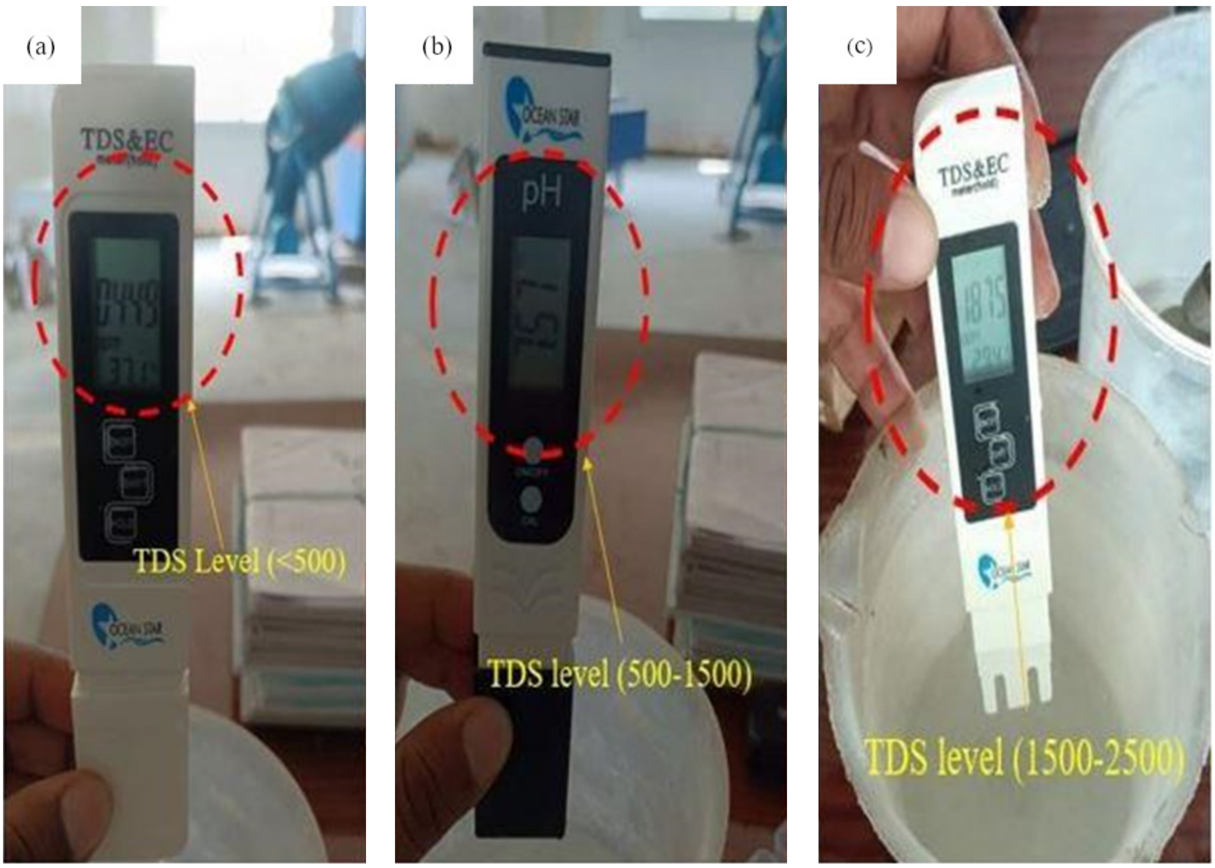

Fig. 2 Various TDS levels for tests (a) less than 500 ppm, (b) 500–1500 ppm, (c) 1500–2500 ppm

balance required to optimize these effects, demonstrating that both under- and oversaturation of TDS can impact the setting behavior of cement paste.

4.3 Compressive strength of the cement mortar

The compressive strength of cement mortar with a 1:3 ratio of PPC is typically resolved through laboratory testing. However, the exact compressive strength may diverge depending on critical determinants such as the quality of the materials used and the curing conditions adopted. Fig. 3 depicts the failure pattern of each sample at various total dissolved solids (TDS) levels, with a constant 0.5% of Recron fiber. For CM-1, the compressive strength without fibers escalated from 5.1 MPa at 7 days to 10.6 MPa at 28 days, whereas with fibers, it escalated from 7.95 MPa to 12.23 MPa over the consistent period. Similarly, CM-2 elevated from 5.8 MPa to 10.7 MPa without fibers, and from 9.18 MPa to 13 MPa with fibers. The witnessed enhancement in the compressive strength of the mortar with increasing TDS content can be attributed to the effective utilization of pore spaces within the cement mortar matrix. When TDS is incorporated into the cement mortar mixture, the particles of dissolved solids and Recron 3s fiber begin to occupy the pores within the cement paste. This process enhances the density and overall integrity of the cement mortar, contributing to a notable 25% increase in compressive strength. The initial filling of pores by TDS particles and fibers effectively reduces voids, resulting in a more compact and robust structure. CM-3 progresses from 5 MPa to 11 MPa without fiber, and 9.18 MPa to 12.95 MPa with fiber. Finally, CM-4 without fibers moves from 5.1 MPa to 10 MPa, and that with fibers moves from 9.18 MPa to 12.97 MPa.

These results demonstrate that the inclusion of Recron fibers consistently enhances the compressive strength of cement mortar at all measured intervals, with the most significant improvements observed at 28 days. Compared with conventional mortar, fiber-reinforced mortar has a

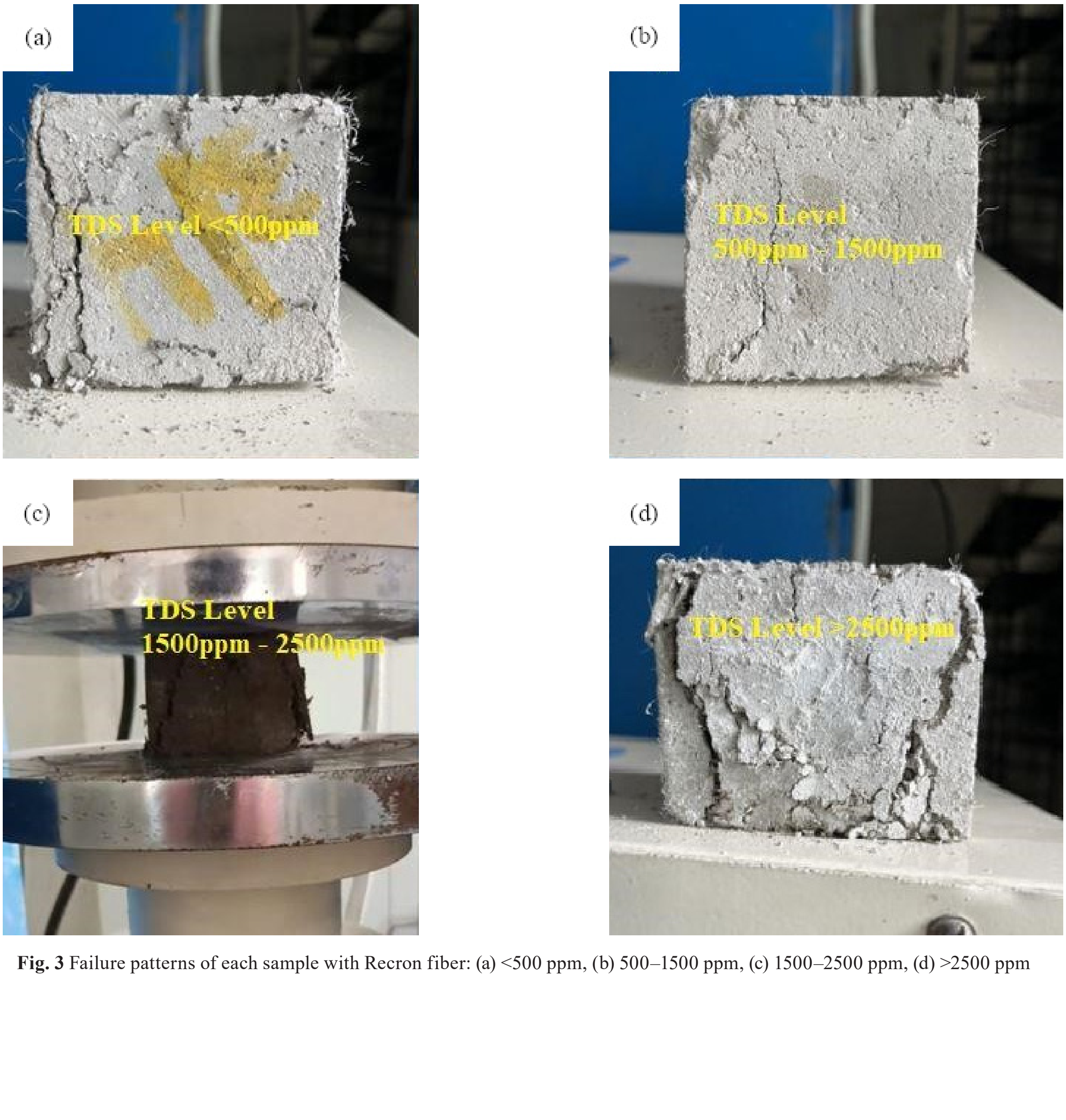

Fig. 3 Failure patterns of each sample with Recron fiber: (a) <500 ppm, (b) 500–1500 ppm, (c) 1500–2500 ppm, (d) >2500 ppm

standard increase in compressive strength of approximately 15.4% to 29.7%. The strength of fiber-modified mortar is greater than that of conventional mortar. Compared with the conventional mortar, the mortar with fibers and a ppm range of less than 500 has a 15.38% high compressive strength. The comparison highlights that the ppm range between 500 and 1500 is 21.5%, 1500 and 2500 is 17.73%, and the range above 2500 is 29.7%. Nanda et al. [48] examined the outcome of fly ash, metakaolin, and Recron 3s fibers on concrete and derived the optimal replacement with 10% metakaolin where its compressive, split tensile, and flexural strength gets increased by 10.25%, 9.46%, and 12.34%, sequentially, with 0.2% 3s fibers. Combining 10% fly ash and 5% metakaolin resulted in improvements of 6.92%, 4.50%, and 3.83%, respectively. Fig. 4 and Fig. 5 depict the variations of compressive strength in cement mortar. It indicates that sample CM2 had a higher compressive strength than other samples, likely due to the increased ionic presence in the water. This phase of saturation with TDS is beneficial up to 1500 ppm, beyond which the compressive strength commences to decline. As the TDS content persists to lift, the pores within the cement mortar become saturated with chloride ion particles. Once it attains the saturation point (1500–2500 ppm), no further positive outcomes are noted on the compressive

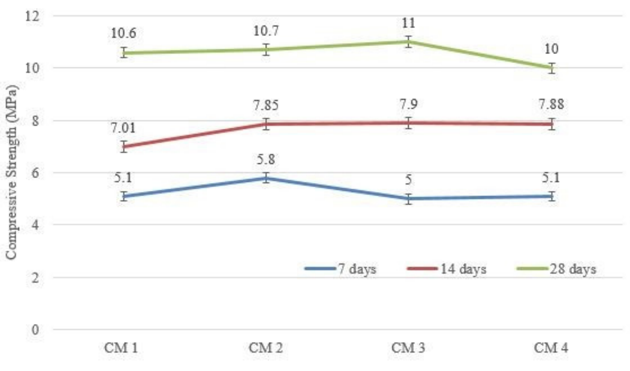

Fig. 4 Compressive strength of conventional cement mortar

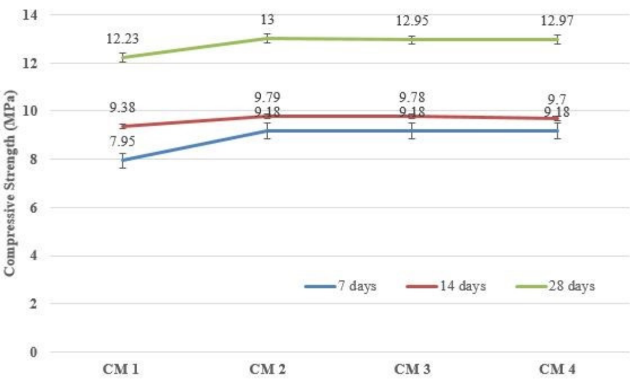

Fig. 5 Compressive strength of cement mortar with Recron fibers

strength. Alternatively, the excess TDS particles, which cannot be accommodated within the already saturated pores, begin to exert adverse physical and chemical influences on the cement mortar. These surplus particles physically disrupt the homogeneity of the cement mortar mixture, creating weak spots and inconsistencies within the matrix. Specifically, excess chloride ions interact with the hydration products of cement, potentially leading to the formation of unwanted compounds that trade off the integrity of the cement mortar. The high salt content increases the brittleness of the mortar, leading to a reduction in strength at elevated TDS levels. The detrimental effects of excessive TDS content are multifaceted. Physically, extra particles can hinder the proper binding of cement particles, leading to a less cohesive mixture. This results in a reduction in the overall strength of the cement mortar, as the structure becomes more porous and less dense. Chemically, the existence of excess TDS can modify the hydration process, potentially leading to the formation of compounds that are not conducive to the strength and durability of the cement mortar. For example, certain salts in TDS can react with the hydration products of cement, forming expansive compounds that cause cracking and spalling over time. Overall, while the initial increase in TDS content (500–1500 ppm and 1500–2500 ppm) can increase the compressive strength of cement mortar by effectively filling the pores and increasing the density, exceeding a 2500 ppm level of TDS drives to saturation of the pores. Beyond this point (>2500 ppm), additional TDS particles disrupt the cement mortar matrix both physically and chemically, resulting in a declined compressive strength. Nanda et al. [48] optimized the strength of cement mortar to retain the TDS content within an optimal range that maximizes the strength without reaching the saturation threshold.

4.4 Water absorption test

The variation in water absorption in cement mortar with varying concentrations of total dissolved solids (TDS) in the mixing water is depicted in Fig. 6. The plot in Fig. 6 illustrates a noticeable trend where the water absorption of the cement mortar slightly increases with the TDS content Specifically, the recorded water absorption values for the cement mortar mixtures labeled CM-2, CM-3, and CM-4 are 3%, 4.9%, and 8% lower, respectively, than those of the conventional cement mortar without recurrent fibers. The observed increase in water absorption with increasing TDS content is attributed to the pore-filling ability of the

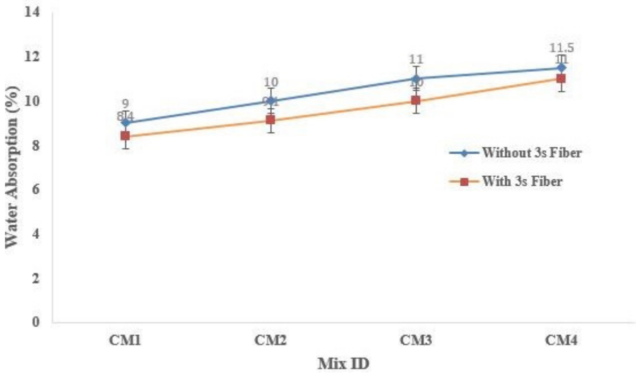

Fig. 6 Variations in water absorption

fine particles present in the total dissolved solids. As the TDS content in the mixing water increases, dissolved solids particles and fibers effectively fill the voids and pores within the cement mortar matrix. This pore-filling action principally reduces the overall porosity of the cement mortar, making it less permeable to water. Specifically, when cement mortar is mixed with water containing higher levels of TDS (1500 ppm to 2500 ppm), the dissolved solids contribute to filling the micropores and capillaries within the cement paste. These particles occupy spaces that would otherwise be filled with water or air, resulting in a denser and less porous cement mortar structure. This densification of the cement mortar matrix is beneficial for reducing water absorption, as there are fewer voids and channels through which water can infiltrate. The reduction percentages of 3% for CM-2, 5% for CM-3, and 9% for CM-4 indicate that as the concentration of TDS increases, the effectiveness of pore filling becomes reduced. In the range of 1500 ppm to 2500 ppm (TDS), finer particles are available to occupy the micropores, thereby further reducing the porosity and subsequently the water absorption capacity of the cement mortar. Moreover, the finer TDS particles act as additional binding agents within the cement mortar, contributing to a tighter and more compact structure. This compactness not only reduces water absorption but also enhances the durability of the cement mortar by limiting the pathways available for water and other potentially harmful substances to penetrate and cause deterioration. As a result, increasing the TDS content in the mixing water led to a gradual reduction in water absorption in the cement mortar because of the homogeneous dispersion of the cementitious C-A-H and C-S-H gels.

This reduction is primarily due to the pore-filling capability of the fine TDS particles, which decreases the porosity of the cement mortar. Deshpande et al. [10] and Nanda et al. [48] reported that cement mortar with 3s fibers have a relatively high rate of strength and durability gain. Similarly, Aldayel Aldossary et al. [49] reported that controlling the TDS content enhances the impermeability and durability of cement mortar by reducing its water absorption capacity.

4.5 Water permeability test

Despite the higher total dissolved solids (TDS) content in the mixing water resulting in reduced water absorption due to the pore-filling action of TDS particles, a slight increase in water permeability was observed. Fig. 7 illustrates that the highest water permeability was measured in CM-3 cement mortar, which exhibited a permeability nearly 18% higher than that of CM-1 and conventional cement mortar. Moreover, the permeabilities of the other mixtures were similar to those of the control cement mortar, with CM-2 and CM-4 being 8% and 12% greater than CM-1, respectively. This increase in water permeability, despite lower water absorption, can be attributed to the complex interplay between the pore structure and the presence of TDS particles and Recron fibers. While the fine particles of TDS effectively fill the pores, reduce the overall porosity, and thereby decrease water absorption, they may also cause discontinuities or microcracks within the matrix. These microcracks can facilitate pathways for water to penetrate, thus slightly increasing the permeability of the cement mortar. The recorded water penetration depth values for all four cement mortar mixtures with different TDS contents were far below 30 mm. According to IS 3085 [51], these values indicate that the water permeability of all mixtures can be rated as "low." This rating suggests that, despite the variations in TDS content and the observed increase in permeability for certain mixtures, the overall resistance of the cement mortar to water penetration remains durable because of the homogeneous

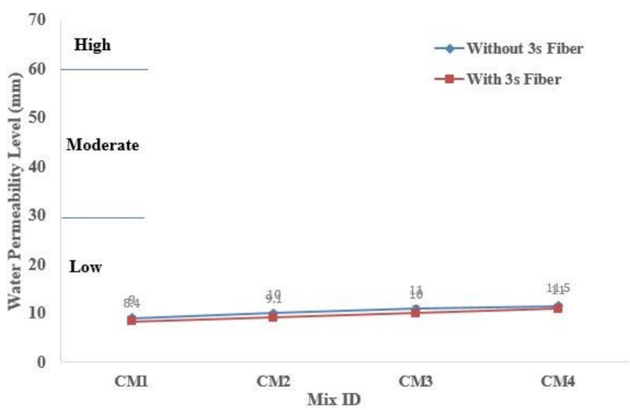

Fig. 7 Variations in water absorption

dispersion of cementitious C-A-H and C-S-H gel. This proves that higher TDS concentrations do not adversely affect the resistance of cement mortar to water permeability to a significant extent. The pore-filling ability of TDS particles enhances the density of the cement mortar matrix, leading to reduced water absorption, whereas a slight increase in permeability does not compromise the overall resistance of the cement mortar to water ingress. In contrast to the findings of Halder et al. [16], the findings emphasize the potential for using water with varying TDS concentrations in cement mortar mixtures without significantly affecting durability or resistance to water-related deterioration. Aldayel Aldossary et al. [49] reported that this balance between reduced water absorption and slightly increased permeability while maintaining a low overall penetration depth highlights the complexity of the effects of TDS on cement mortar properties and the need for a nuanced understanding of these interactions in cement mortar mix design.

4.6 Flexural strength test on cement mortar

The flexural strength test results of the cement mortar containing Recron fibers summarized in Table 5, and the crack and failure pattern shown in Fig. 8, illustrate the performance across different mix designs at various curing periods. Mix CM 1 exhibited a flexural strength of 3.0 MPa at 7 days, which increased to 3.9 MPa at 14 days and reached 4.9 MPa at 28 days. In comparison, mix CM 2 demonstrated a superior flexural strength, starting at 4.0 MPa at 7 days, advancing to 4.4 MPa at 14 days, and peaking at 5.7 MPa at 28 days.

This indicates a consistent improvement over CM 1 at each curing stage. Among all the tested mixes, CM 3 had the highest flexural strength, beginning at 4.9 MPa at 7 days, increasing to 5.4 MPa at 14 days, and attaining 6.1 MPa at 28 days. This mixture significantly outpaced both CM 1 and CM 2, particularly at the 28-day mark, where CM 3's flexural strength was 1.2 MPa greater than that of CM 2 and 1.4 MPa greater than that of CM 1. Conversely, CM4 started with a flexural strength of 3.1 MPa on day 7, which

Table 5 Flexural test results of the cement mortar with Recron fibers

S.No.	Mix ID	Flexural strength of prism with Recron fiber (MPa)		
		7 days	14 days	28 days
1	CM 1	3.0	3.9	4.9
2	CM 2	4.0	4.4	5.7
3	CM 3	4.9	5.4	6.1
4	CM 4	3.1	4.2	4.7

Fig. 8 Prism with various TDS levels (a) <500 ppm (b) 500–1500 ppm (c) 1500–2500 ppm

increased to 4.2 MPa on day 14 but then only slightly increased to 4.7 MPa on day 28. While the performance of CM 4 was initially better than that of CM 1, its growth rate slowed after 14 days, resulting in a lower 28-day strength than those of the other mixes. This finding indicates that CM 4 did not sustain the same level of strength development as CM 2 and CM 3 noticed, highlighting a less effective combination of ingredients or curing conditions for optimizing flexural strength. In summary, the data reveal that CM 3, with flexural strengths of 4.9 MPa, 5.4 MPa, and 6.1 MPa at 7, 14, and 28 days, respectively, is the most robust mix design among the tested samples. This underscores the importance of selecting appropriate mix proportions and additives to achieve optimal performance in cement mortar applications.

4.7 FTIR analysis

The Fourier Transform Infrared (FTIR) analysis provides critical insights into the molecular composition of cement mortar samples by analyzing specific vibrational modes of the chemical bonds within the material. The FTIR spectra of the four cement mortar samples (CM1, CM2, CM3, and CM4) reveal distinct peaks within the wave number range of 400 to 550 cm^{-1}, which are indicative of the vibrational modes associated with certain functional groups and compounds typically present in cementitious materials. For CM1, the FTIR spectrum displays a significant peak at 521.48 cm^{-1}, with a lower wave number extending to 407.34 cm^{-1} (Fig. 9). This range typically corresponds to the vibrational modes of Si-O bonds, which are characteristic of silicate compounds such as those found in the cement matrix. The broader range suggests the presence of multiple overlapping vibrational modes, possibly

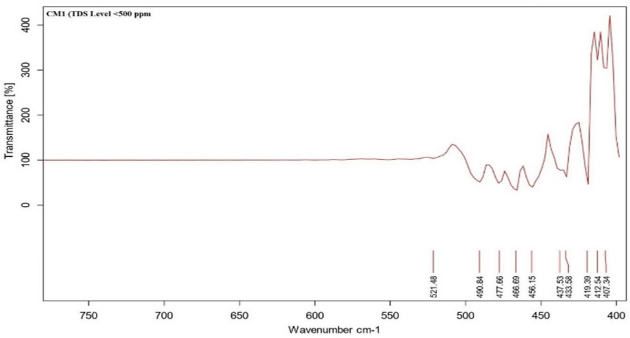

Fig. 9 FTIR results for CM1 samples

indicating a complex silicate structure or the presence of various silicate phases in the mortar. The identification of this broad peak is crucial as it indicates the structural integrity and the presence of hydrated phases within the cement mortar. Fig. 10 exhibits a peak at 521.20 cm^{-1}, which is very close to the peak observed in CM1. This similarity suggests a consistent presence of silicate structures across both samples. The proximity of these peaks in CM1 and CM2 indicates a similar composition of silicate phases, which could imply uniformity in the cement formulation or similar curing conditions during the preparation of these samples. This peak reaffirms the presence of Si-O stretching vibrations, reinforcing the structural stability of the silicate compounds in the cement mortar. In Fig. 11, the peak appears at 499.53 cm^{-1}, slightly lower than in CM1 and CM2. This shift in the wavenumber might indicate a variation in the bond strength or a different silicate composition compared to the previous samples. The lower wavenumber suggests that the Si-O bonds in CM3 might be weaker or involve a different silicate structure, such as a more polymerized or less crystalline phase. This could be due to differences in the raw materials used, variations in the hydration process, or different curing conditions.

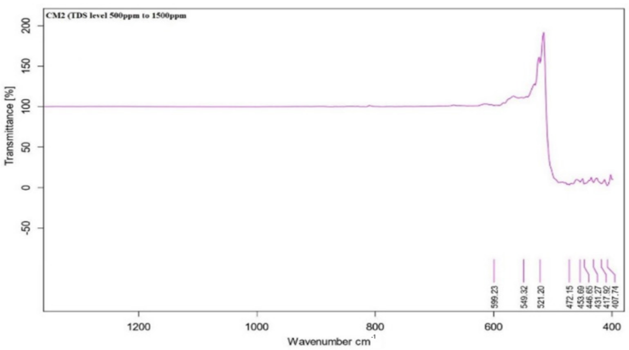

Fig. 10 FTIR results for CM2 samples

The presence of a lower peak could also suggest partial substitution of Si by other elements like Al, affecting the overall bond environment. Fig. 12 shows the highest peak wavenumber at 523.46 cm^{-1}, indicating a slight shift towards a stronger Si-O bond compared to the other samples. This higher wavenumber could be attributed to a more crystalline structure or the presence of a higher proportion of well-ordered silicate phases within the sample. The shift might also reflect a more complete hydration process, resulting in a denser and more structurally stable mortar. This peak suggests a more robust network of silicate chains, which could enhance the overall mechanical properties of the mortar, such as its compressive strength and durability. The FTIR analysis across the four samples highlights variations in the silicate structures within the cement mortars, as indicated by the different peak wavenumbers. These variations can be linked to differences in the chemical composition, degree of hydration, and curing conditions of the mortars. The wave number ranges from 400 to 550 cm^{-1}, associated with the Si-O bond vibrations, is critical in assessing the structural integrity and phase composition of the cement mortar. The slight variations in peak positions between the samples suggest that even minor variations in the formulation or processing of cement mortars can significantly impact their microstructure and, consequently, their mechanical properties.

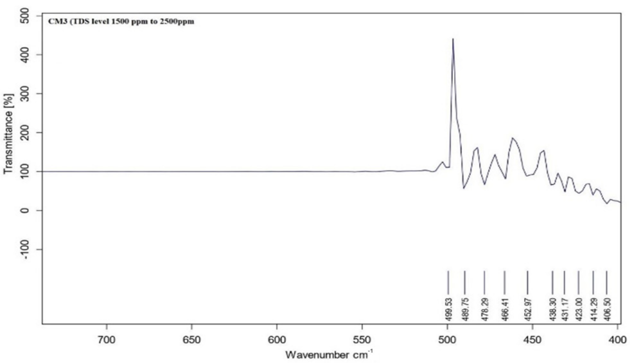

Fig. 11 FTIR results for CM3 samples

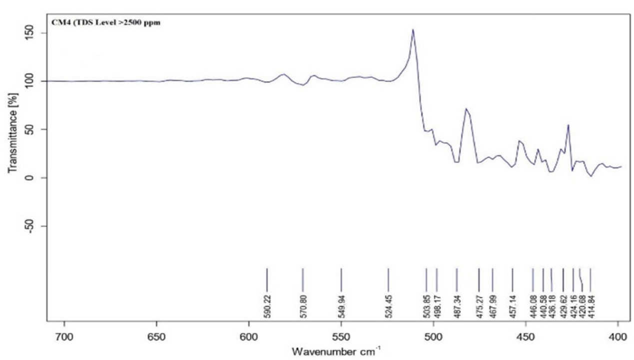

Fig. 12 FTIR results for CM4 samples

4.8 SEM and EDS

The cement matrix exhibits uneven distribution of calcium hydroxide (CH) crystals and calcium silicate hydrate (C-S-H) gels. The red box highlights the porosity of the material, which is indicated by the existence of voids, which are shown as dark areas in the image. Furthermore, a visible cut in the structure has been found. The van der Waals forces between the solid components' surfaces are the main factor affecting the cement paste's solid phase strength. The bonding strength inside the wet cement matrix is greatly influenced by these intermolecular interactions. High lateral surface area in CH crystals improves their adhesive qualities and the material's overall structural integrity. In addition, Fig. 13 shows less porosity and a greater degree of cohesiveness than the control combination (*C*). This implies a microstructure that is denser, which would result in better mechanical performance. Additionally, Fig. 14 shows that the sample's Si, Ca, and O concentrations are higher than those of the control sample (*C*), which may help the cementitious material's strength and durability properties.

5 Conclusions

The research comprehensively examined the influence of concentration of total dissolved solids (TDS) on the properties of cement mortar while hydrating, involving setting time, flowability, compressive strength, water absorption, and permeability, with a consistent addition of 0.5% Recron fiber. The findings reveal diverse key insights into the effects of TDS on cement mortar, highlighting both beneficial and adverse impacts based on concentration:

1. The setting time of the cement mortar was substantially affected by the TDS content in the mixing water. Chloride ions within the TDS accelerated the hydration reaction, reducing the setting time. Additionally, higher solid particle concentrations facilitated increased contact between cement grains, further accelerating the setting process. The optimal setting times were observed at TDS concentrations of 1500–2500 ppm. However, excessively high TDS concentrations (>2500 ppm) led to a slight increase in setting time due to potential flocculation, indicating a delicate balance in TDS levels for optimal performance.
2. The flow table test demonstrated that the cement mortar's flowability remained within the standard range of 105% to 115%, regardless of the addition of fibers or variations in the TDS concentration. This consistency indicates that the modifications to the mortar, including fiber incorporation and varying water quality, had no adverse effect on its workability, ensuring suitability for practical construction applications.
3. In terms of compressive strength, the experimental data reveal a significant increase in the performance of fiber mortar compared with that of conventional mortar. Specifically, the mortars with Recron fibers presented higher compressive strengths across all the ppm water ranges tested. Compared with that of conventional mortar, the compressive strength of fiber-reinforced mortar with less than 500 ppm was 15.38% high compressive strength. Similarly, fiber mortars within the ppm ranges of 500–1500, 1500–2500, and above 2500 presented strength improvements of 21.5%, 17.73%, and 29.7%, respectively, over their conventional counterparts. These findings indicate that the inclusion of Recron fiber at a constant 0.5% significantly enhances the mechanical properties of cement mortar.
4. A higher TDS content resulted in reduced water absorption due to the pore-filling capacity of fine TDS particles, which decreased the overall porosity of the cement mortar. Despite this reduction in water absorption, a slight increase in water permeability was observed at higher TDS levels, likely due to microcracks or discontinuities

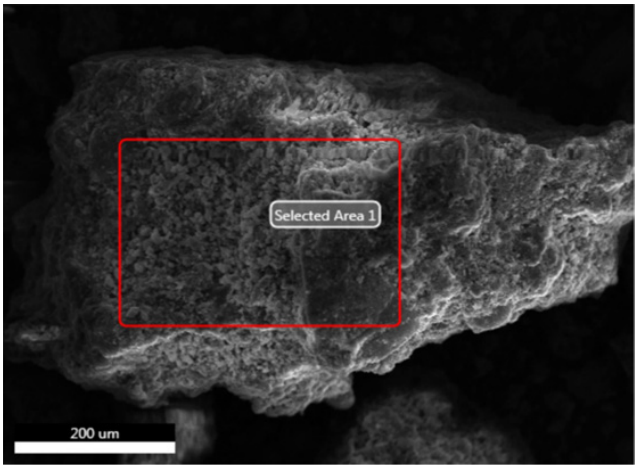

Fig. 13 SEM image

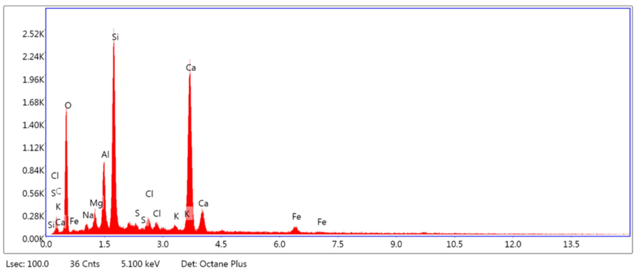

Fig. 14 EDS results for CM2 sample

introduced by the TDS particles. Nevertheless, all the mixtures maintained a "low" water permeability rating, indicating that the increased permeability did not significantly compromise the resistance of the cement mortar to water ingress.
5. The FTIR analysis of cement mortar samples reveal variations in silicate structures, indicated by different peak wavenumbers in the 400 to 550 cm^{-1} range. These differences suggest varying degrees of hydration and bond strengths, which impact the mortar's structural integrity and are crucial for optimizing its mechanical properties and durability.

The research summarizes that the presence of TDS in mixing water can beneficially affect cement mortar properties up to a concentration of 2500 ppm. The optimal TDS concentration (>2500 ppm) enhances the setting time, compressive strength, and water absorption attributes. However, exceeding these levels can be detrimental, underscoring the importance of careful TDS management in cement mortar mix design.

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Data availability
The data that support the findings of this study are available from the corresponding author (Mohanraj Rajendran) upon reasonable request.

Author contribution
Conceptualization, Methodology, Investigation: Mohanraj Rajendran, Murugan Lokeshwaran; Funding acquisition, Resources, Supervision, Writing—original draft preparation and editing: Mohanraj Rajendran; Writing—review and editing: Mohanraj Rajendran, Murugan Lokeshwaran, Ubagaram Johnson Alengaram, Ashwathi Rajendran. The final draft of the manuscript has been read and approved by all contributors.

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