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An experimental study on modification of pervious concrete properties using polyacrylamide

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ABSTRACT

This study tends to use polyacrylamide (PAM) as a potential cement replacer for the enhancement of pervious concrete properties. The study considers four different replacement percentages and compares them with a zero-percentage replacement mix. The properties that were analysed in the fresh state before hardening include slump value, flow percentage, and fresh density of the mix. The analysis also includes further hardened properties such as water absorption, density, infiltration capacity, porosity, and abrasion resistance In addition, compressive strength under two different curing conditions, namely water curing and air curing. is analysed. Microstructural analysis is further performed using FTIR, XRD, and SEM/EDAX to confirm the experimental analysis. The results indicate a 12% increase in the maximum compressive strength in the mix with 0.5% replacement compared to the reference mix. Strength analysis also reveals that the polymer acts as a retarder. Using PAM to replace cement reduces water absorption, density, porosity, and infiltration capacity. In addition, the water treatment ability of various pervious concrete specimens is also analysed in terms of Total Suspended Solids (TSS), Chemical Oxygen Demand (COD). Total Phosphates (TP), Total Nitrogen (TN), Biochemical Oxygen Demand (BOD) and Total Organic Carbon (TOC). Results show that TP removal was as high as 82.5% in a mix with 2% replacement. Therefore, PAM can be regarded as a potential partial cement replacer in pervious concrete.

1 Introduction

The practice of incorporating polymers into construction materials has been in place for the past few decades. Cement's increased pollution during production and application encourages this practice. In addition, increased demand for construction materials has also encouraged the usage of various Supplementary Cementitious Materials (SCMs) one of which is polymers [1-2].

The polymers used in construction can either be natural polymers like cellulose, chitosan etc., or synthetic polymers. Regardless of the polymer type, numerous studies demonstrate that adding polymer binding properties to cement in the Interfacial Transition Zone (IRZ) improves its mechanical properties [3]. In addition to the enhancement in strength, polymer usage even alters the rheology of cement, consequently affecting the other mechanical and durability properties of various construction materials [4–5]. Construction materials can incorporate polymers in a variety of ways. Some studies use polymers as a partial replacement for binder, while others apply them as surface coatings to strengthen their resistance against changing atmospheric conditions [6]. For instance, Chen et al. (2020) [7] have proposed the use of biopolymer chitosan as an additive to Alkali-activated slag-pervious concrete. Results show that chitosan serves as an effective additive for construction materials. Likewise, many other polymers can potentially improve the properties of construction materials in various aspects. One such polymer is Polyacrylamide (PAM).

Laboratories prepare PAM, a water-soluble polymer with the chemical formula $(CH2CHCONH2)_n$. Various earlier studies reveal that the use of PAM as an additive or replacement in construction materials is beneficial in various aspects. Zhi et al. (2020) [8] in their study have determined that PAM, when added to concrete, has enhanced the corrosion-inhibitive property of steel. This study showed that the addition of PAM to a simulated solution of concrete

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enhances the corrosion resistance by forming an adsorptive layer on the steel surface. Another study by Li et al., (2020) [9] shows that adding PAM to mortar can improve its cracking resistance. The study reveals that the key factor for improving cracking resistance is the intermolecular hydrogen bonding between cement and acrylamide. The earlier studies suggest that PAM chemically reacts with the binder material to enhance the properties of concrete, steel, mortar, and other construction materials.

Other than the construction industry, PAM has another application in wastewater treatment. Like every other polymer, the active functional groups in PAM possess chelating ability, aiding in flocculative removal of various contaminants when used in wastewater treatment either individually or in combination with some other component [10–11]. Zhao et al. (2015) [12] used PAM as a draw solute in the forward osmosis process in another study. As a result, wastewater treatment properties, along with improved mechanical stability, make the polymer suitable for pervious concrete.

Pervious concrete is an eco-friendly material that has enormous porosity due to its low quantity of fine aggregates. This concrete finds its application in storm water infiltration and pavements as per the ACI 522, 2010 report [13]. The report further indicates that the nominal infiltration capacity, porosity, and compressive strength of pervious concrete mixes range from 0.14 to 1.22 cm/s, 15 to 35%, and 2.8 to 28 MPa, respectively. Despite the lower load-bearing capacity, the other properties of pervious concrete are quite desirable, thereby finding application in evaporative cooling, vehicular noise management, friction reduction, slope stability, etc. Thus, various methods are adapted for enhancement of the compressive strength of the mix without disrupting its basic properties to a greater extent [14–16]. Pervious concrete is also used for wastewater purification. Various studies show that pervious concrete has the ability to purify wastewater. This property thereby aids in the proper recharge of groundwater while simultaneously maintaining its quality [17–18]. Thus, in a broad sense, this paper aims to utilise PAM in pervious concrete to improve its various properties.

The specific objectives of the study include analysing the effects of replacing cement with Polyacrylamide (PAM) in pervious concrete. Effects on pervious concrete are analysed in terms of fresh (Density and Workability) and hardened concrete properties (Water absorption, density, abrasion resistance, porosity, and infiltration capacity). The effects of alternate curing conditions (water and air) on compressive strengths are analysed after the 7th, 14th, and 28th days of curing. Furthermore, microstructural analysis is performed on dried hydrated cement samples using FTIR (Fourier Transform Infrared Spectroscopy), XRD (X-ray Diffraction), and SEM/EDAX (Scanning Electron Microscopy/Energy Dispersive X-ray Analysis). Water purification ability of various samples is determined considering Total Suspended Solids (TSS), Total Phosphates (TP), Total Organic Carbon (TOC), Total Nitrates (TN), Chemical Oxygen Demand (COD), and Biochemical Oxygen Demand (BOD) as defining parameters.

2 Materials and Methods

2.1 Material Collection and Analysis

Commercial sources supply PAM, which serves as a substitute for cement. PPC (Portland Pozzolanic Cement), confirming IS 1489 (Part 1):1991 [19], is used as a binder. Test procedures from IS 4031 (Parts 4 and 5): 1988 [20-21] are adapted for confirmation of the basic properties of binder. Earlier studies show that the use of coarse aggregate and binder in the ratio 4:1 gives good compressive strength in comparison to other ratios [22]. The water cement ratio of 0.40 was adapted and maintained constant throughout the study. The coarse aggregates used are blue granite stones of 12mm in uniform size that ensure the development of the required permeability [23]. We use 10% (by weight of binder) of M. sand as the fine aggregate. Both the aggregates are procured commercially and are analysed as per the procedure entitled in IS 2386 (Parts 3 and 4):1963 [24–25] and are found to be in line with the specifications entitled in IS 383:1970 [26]. We use normal tap water that meets the usual IS standards for mixing and curing purposes. The study does not include any admixtures. Table 1 displays the mix ratios for mixes with and without replacement.

2.2 Experimental methodology

A post-basic analysis of material mixes with five different ratios is prepared, out of which one mix stands as a reference with zero percentage replacement. Further, four different mixes with polyacrylamide polymer replacing cement in percentages of 0.5%, 1%, 1.5%, and 2% are adapted.

The mix undergoes analysis for fresh properties, specifically workability and fresh density, prior to hardening. Workability is measured in terms of slump value and flow percentage, adapting standard methodology from IS 1199:1959 [27]. Similarly, fresh density is analysed using the procedure specified in ASTM C 1688 (2014) [28], and values are tabulated.

After analysis of fresh properties, 90 cubic samples of size 100mm are cast for determination of compressive strength. Two different curing conditions, viz, water, and air curing are adapted to analyse the effects of polyacrylamide in both curing conditions. Since the coarse aggregates used have a uniform size of less than 20mm, cubes of 100mm size can be used for the determination of strength as per IS 516:2018 [29]. Compressive strength after curing for 7, 14, and 28 days is analysed for both curing conditions. Strength is analysed using a Universal Testing Machine (UTM) with a model number of TVE-CN-600 made by Hitech India Equipment.

Table 1 Mix ratios for Pervious concrete mixes with and without replacement

S. No.	Sample ID	Cement (kg/m^3)	M-Sand (kg/m^3)	Coarse Aggregate (kg/m^3)	Replacement (kg/m^3)
1	1	370	37	1480	0
2	4A	368.15	37	1480	1.85
3	4B	366.3	37	1480	3.7
4	4C	364.45	37	1480	5.55
5	4D	362.6	37	1480	7.4

The cubes are also tested for other hardened properties, namely density and porosity, adapting the procedures outlined in ASTM C 1754 (2012) [30]. In addition, the water absorption of the cubes is also determined by adapting the procedure from Shah and Pitroda (2014) [31].

The sand blasting technique, as described in IS 9284:1979 [32], determines the durability of the cubic specimens in terms of their resistance to abrasion. Analyses are performed in triplicate to ensure stability in the readings obtained.

The other primary parameter, namely the infiltration capacity of pervious concrete sample, is analysed using the procedure from ASTM C 1701 M-09 [33]. This test is named the modified infiltration capacity test and is specifically performed in laboratory conditions. This analysis requires cylindrical samples of size 100 x 200mm. Samples of the required size are cast using PVC moulds with a height of 220mm. This extension is adapted to ensure the maintenance of a standard head of 10mm as described in Haselbach et al., (2017) [34]. Tests are carried out not before pre-wetting the samples to ensure a similar saturation condition in all the specimens.

After the post infiltration capacity test, the same cylindrical samples are used for the analysis of the wastewater purification capacity of pervious concrete, simulating the infiltration of contaminated rainwater. Wastewater samples are collected from the Effluent Treatment Plant at SSN College of Engineering, Tamil Nādu, India. Samples were collected on three consecutive days and analysed for the parameters COD, TOC, TSS, BOD, TN, and TP. The initial characteristics of the raw wastewater sample were similar for almost all three days, with a negligible difference of ±50 ppm. Raw wastewater characteristics in terms of TSS, TP, TN, BOD, TOC, and COD in mg/l are 115, 85.8, 23.1, 462.63, 261.67, and 833, respectively. In this study, we measure TP, TN, and TSS using a DR-9000 reactor from Hach. A 5-day BOD value is considered here and can be measured using the standard Respirometric method using the BODTrak^{TM}II apparatus, whereas the DRB 200 reactor from Hach is used to measure COD and TOC. Adapting (1) determines the removal efficiency of the mixes.

$$\text{Removal efficiency} = \frac{C_i - C_o}{C_i} \text{ X } 100 \qquad (1)$$

3 Results and Discussions

3.1 Fresh Concrete properties

3.1.1 Workability

Figure 1 shows the variation of slump value and flow percentage with respect to PAM percentage in various pervious concrete specimens. According to Figure 1, the slump value and flow percentage of the reference mix are 90mm and 81.33%, respectively, indicating that the mix has medium workability [35]. All the mixes, irrespective of replacement, have shown a shear slump. Another major observation from the graph is that the variation in workability of the mix is proportional to the variation in PAM percentage, thereby changing the medium-workable mix to a highly workable mix. The variation in flow percentage matches the variation in slump value. While a 0.5% replacement does not significantly increase the flow percentage, a further increase in the polymer percentage improves the flow. The lubricating effect of the polymer contributes to the enhanced workability of the mix. This result is consistent with the reactions of other water-soluble polymers, which typically improve the fluidity of the mix as a whole [36].

3.1.2 Fresh density

Fresh density results denote that an increase in PAM percentage reduces the density of the pervious concrete in its fresh state. This indicates the lubricating effect of the water-soluble polymer, which is responsible for the reduction in bulk density of the concrete specimens as percentage replacement increases [37]. This observation is consistent with the hardened density observation, shown in Figure 2.

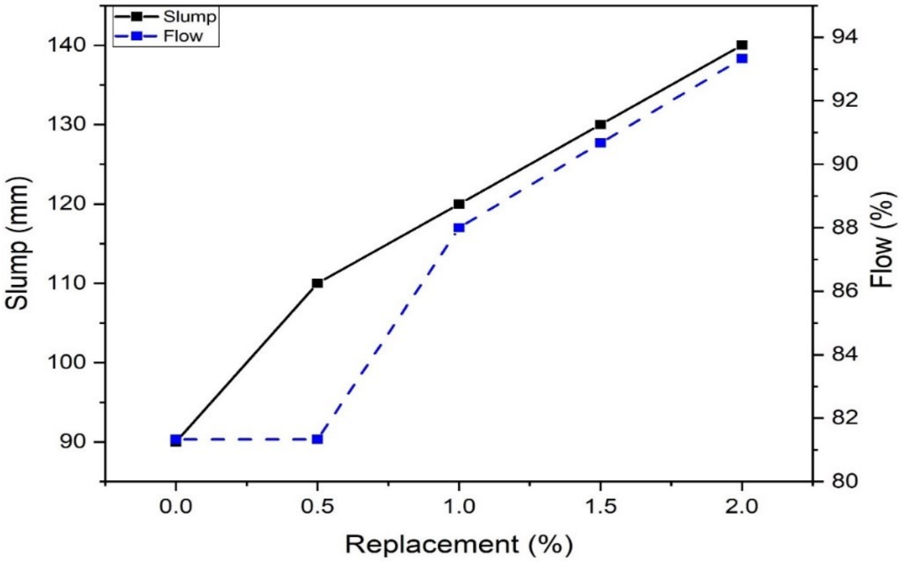


Figure 1. Workability of PAM replaced samples

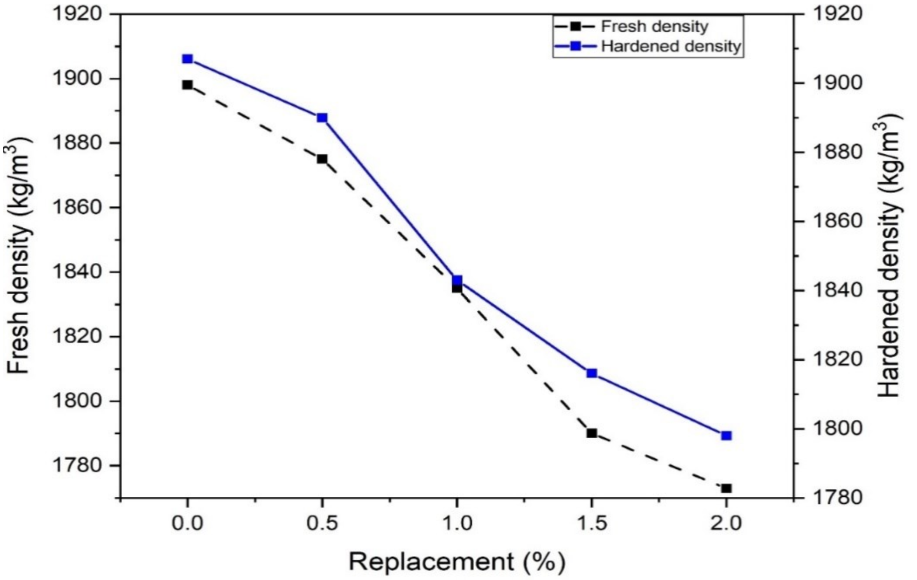


Figure 2. Fresh and hardened density Vs PAM replacement

3.2 Hardened Concrete Properties

3.2.1 Density

Like the fresh density, the hardened density of the mix goes down as the percentage of PAM replacement goes up, as shown in Figure 2. Though hardened density is higher in comparison to fresh density, both follow a similar variation pattern with respect to replacement variation. This slight difference in hardened density from fresh density is nominal, as the variation is less than 2% [38]. Thus, the lubricating and dispersive effects of the water-soluble polymer cause this reduction in density, as discussed in the earlier section.

3.2.2 Porosity

Table 2 shows changes in some hardened properties of pervious concrete mix based on percentage replacement. These properties include water absorption, porosity, percentage abrasion loss, and infiltration capacity. The porosity analysis results show minimal changes in porosity as replacement increases Though the porosity value shows a slight reduction with the increase in replacement for up to 1%, over this level no variation is observed. This is due to the lower percentage of replacement whereas the initial reduction in porosity is mainly due to the dispersion of PAM particles that fill the space amongst coarse aggregates and cement, thereby reducing the porosity of the mix as a whole [39].

3.2.3 Water absorption

Observations from water absorption analyses denote that PAM on replacement tends to reduce the water absorption of the mix. This is because, when cement is replaced with PAM, the polymer particles fill up the minute pores amongst cement and aggregates due to their dispersion properties. This results in a reduction in the free space available for the absorption of water, thereby reducing the water absorption of the mixes [40]. Thus, an increase in the PAM percentage in pervious concrete reduces the mix's porosity while simultaneously reducing its water absorption. Thus, porosity and water absorption follow almost an inverse relationship with respect to replacement percentage, as shown in Figure 3.

3.2.4 Abrasion resistance

Table 2 displays the percentage abrasion loss for samples with varying PAM percentages. The table reveals that the sample without replacement exhibits a higher percentage loss due to abrasion. The abrasion-induced weight loss of 0.32% exceeds the limits set by IS 9284:1979 for concrete specimens [32]. Still, the mix possesses the eligibility for utilisation in footpaths as per standards. An increase in PAM content enhances the mixes' resistance to abrasion. This abrasion resistance, when correlated with porosity, indicates that a decrease in porosity improves the mix's abrasion resistance. These results are similar to those observed earlier in a study by Muthaiyan and Thirumalai (2017) [41]. The water-soluble and dispersive nature of polymer particles makes it easier for coarse aggregates to stick together. This lowers the porosity, which in turn lowers the weaker areas, making the specimens more resistant to wear.

3.2.5 Infiltration Capacity

From the infiltration capacity results depicted in Table 2, it can be inferred that the specified parameter reduces with every 0.5% increase in PAM percentage. Though the infiltration capacity parameter primarily depends on porosity both do not follow a linear relationship. This is because infiltration capacity, in addition to porosity, also depends on pore connectivity [42]. Thus, the reduction in infiltration capacity is explained by the reduction in pore connectivity as the well-dispersed polymer particles fill the pores in pervious concrete specimens, thereby reducing their corresponding infiltration capacities significantly.

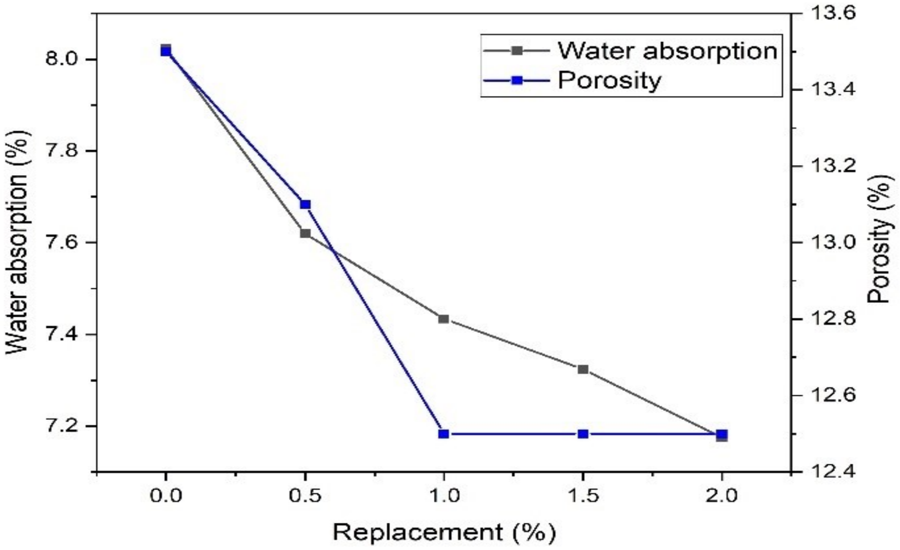


Figure 3. Water absorption and porosity variation with PAM replacement

Table 2. Variation in hardened properties with respect to percentage replacement

S. No.	Replacement (%)	Porosity (%)	Water absorption (%)	Abrasion loss (%)	Infiltration capacity (mm/s)
1	0	13.5	8.023	0.32	7.36
2	0.5	13.1	7.619	0.24	7.35
3	1	12.5	7.434	0.15	5.44
4	1.5	12.5	7.324	0.10	4.62
5	2	12.5	7.175	0.05	4.55

3.2.6 Compressive strength

The effects of PAM on the compressive strength of the sample are analysed under two different curing conditions, namely water curing, and air curing and the readings are tabulated in Table 3. Observations from the results indicate that water curing has a better strength-gaining ability in all samples than air curing, regardless of the replacement percentages. Furthermore, all of the samples show a characteristic increase in strength with respect to curing age.

3.2.6.1 Water curing

When tested after 28 days of curing, samples cured using water according to standard procedures show an increase in strength with a replacement of 0.5% cement. However, a higher number of replacements reduces the strength. PAM on replacement tends to retard the strength-gaining ability of the mix in earlier stages, irrespective of its percentage. This signifies the retarding effect of PAM, which is common for almost all water-soluble polymers [43]. Thus, for all the mixes with PAM strength tested initially, it is low in comparison to the strength of mixes without replacement. However, further curing enhances the strength of the mix with a 0.5% replacement. As the polymer possesses water-retaining ability, it absorbs water, thereby aiding in its hydration. The spread-out polymer particles also help make a membrane around the aggregate particles, which makes it easier for bonds to form in the interfacial transition zone. This aids in an increase in strength [44]. However, despite all the factors, a further increase in PAM reduces the strength since the polymer does not aid in the reduction of porosity as observed in earlier sections. Thus, with not much change in porosity, the reduction in binder content tends to reduce the strength for replacement by over 0.5%. However, more research is required to understand why the strength decreases by 0.5%.

3.2.6.2 Air curing

Strength development in samples that underwent air curing is lower in comparison to water-cured samples. This is primarily due to a lack of water, which reduces hydration. This decrease in hydration lowers the compressive strength of the samples. Analogous to water curing, air-cured samples also show very low strength in the earlier stage of curing, signifying that PAM serves as a retarder. From the table, it is evident that mixes with PAM replacement possess a lower strength than the reference mix. However, focusing solely on samples containing polymers, we deduce that PAM replacement leads to an increase in compressive strength during air curing. The strength gets better as the PAM percentage goes up. For air-cured samples made with 1.5% PAM replacement, the highest strength was 3.7 MPa. Despite being only 10% higher than the maximum compressive strength in air-cured samples, this result highlights the water absorption and retention abilities of PAM, which contribute to the self-curing of the samples [45]. However, a further increase to 2% results in a very marginal reduction in compressive strength in comparison to the reference mix. This is due to the reduction in binder quantity as well as the reduction in hydration owing to the low quantity of water available for hydration. Thus, the replacement of cement with PAM shows a significant self-curing ability due to the water absorption and retention capacity.

Table 3. Compressive strengths of Pervious concrete samples with PAM replacement

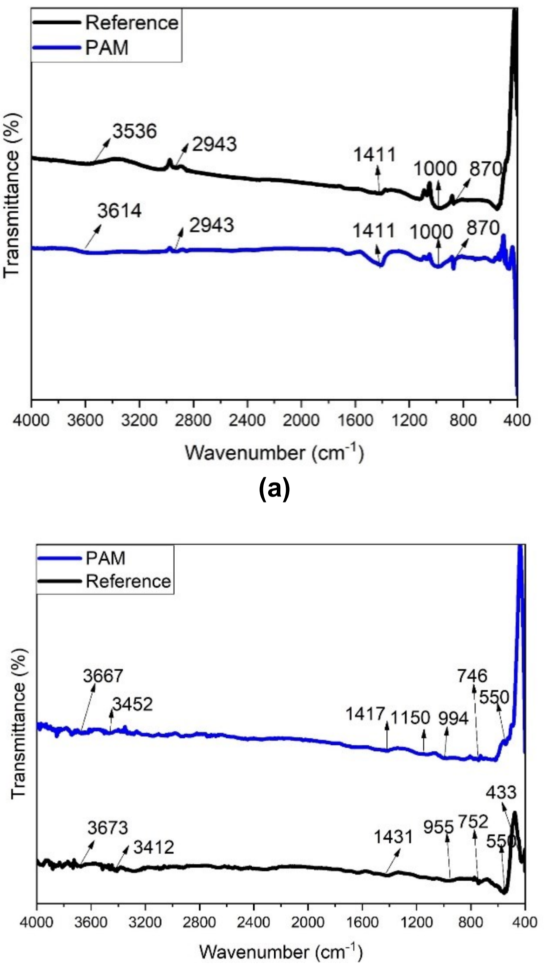
S. No.	Replacement (%)	Compressive strength (MPa)					
		Water curing			Air curing		
		7 days	14 days	28 days	7 days	14 days	28 days
1	0	5.135	6	7.9	2.45	2.98	3.3
2	0.5	4.34	6.06	9	1.64	2.02	2.17
3	1	3.38	4.82	7.7	1.72	1.94	3
4	1.5	2.5	3.64	6.36	2.36	2.52	3.7
5	2	1.8	3.32	4.9	2.54	2.99	3.2

3.3 Micromechanical Analysis

Micromechanical analysis of hydrated cement samples obtained from both curing conditions is performed using FTIR, XRD, and SEM/EDAX. The low replacement percentage explains the lack of remarkable alterations observed for both curing conditions.

3.3.1 FTIR

Figures 4(a) and 4(b) show the variation in FTIR spectra of reference and air-cured samples. As previously discussed, the figures reveal minimal variation in both spectra, with the exception of a few slight shifts and alterations in stretching and bending, due to the lower percentage of replacement. By contrasting the existing peaks in the FTIR spectra of the water- and air-cured reference and PAM mixes, we can observe that all four samples from both curing conditions exhibit similar functional groups. Peaks in the range of 3000 to 4000 cm^{-1} indicate the Hydroxyl group (-OH) which is a characteristic functional group in hydrated cement samples. The presence of hydroxyl groups signifies the hydration of cement after casting pervious concrete samples. In water-cured samples, the peak at 2943 cm^{-1} indicates the presence of a CH bond. Likewise, peaks in the range of 700 to 1500 cm^{-1} signify the presence of alkane and alkyne groups in terms of organic and Si-O, Al-O, and Ca-O when considered in terms of inorganic components. All the bonds signify the presence of Portlandite ($Ca(OH)_2$) and hydrogels (Calcium silicate or Calcium Aluminate (Ca-S-H or Ca-Al-H)), which are characteristic products of hydration obtained from cement. Furthermore, peaks in the range of 400 to 600 cm^{-1} denote the Fe-O functional group, which further indicates the presence of a trace quantity of iron oxide in cement.



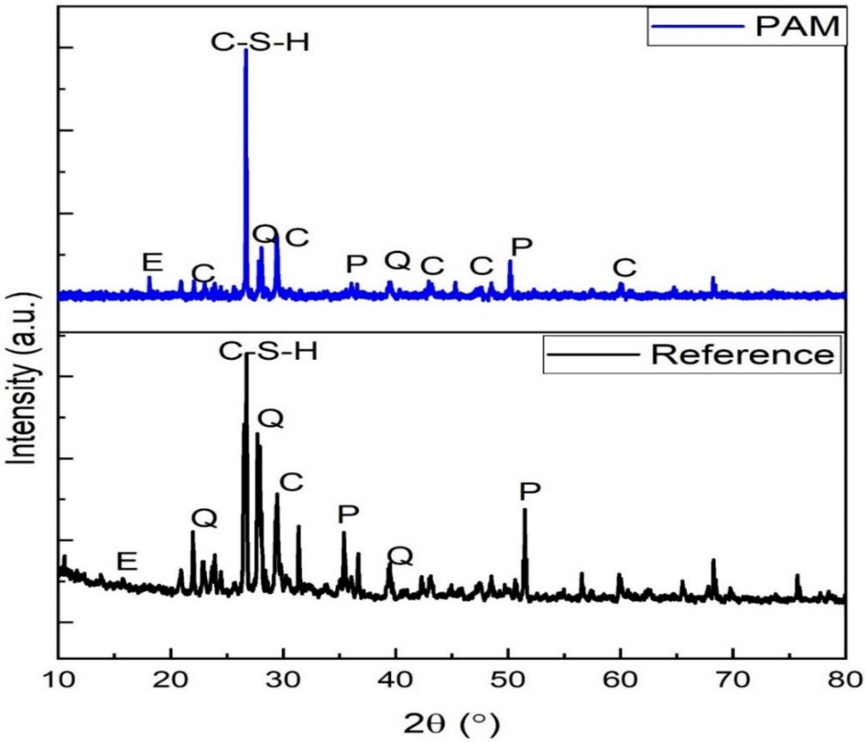
(a)

(b)

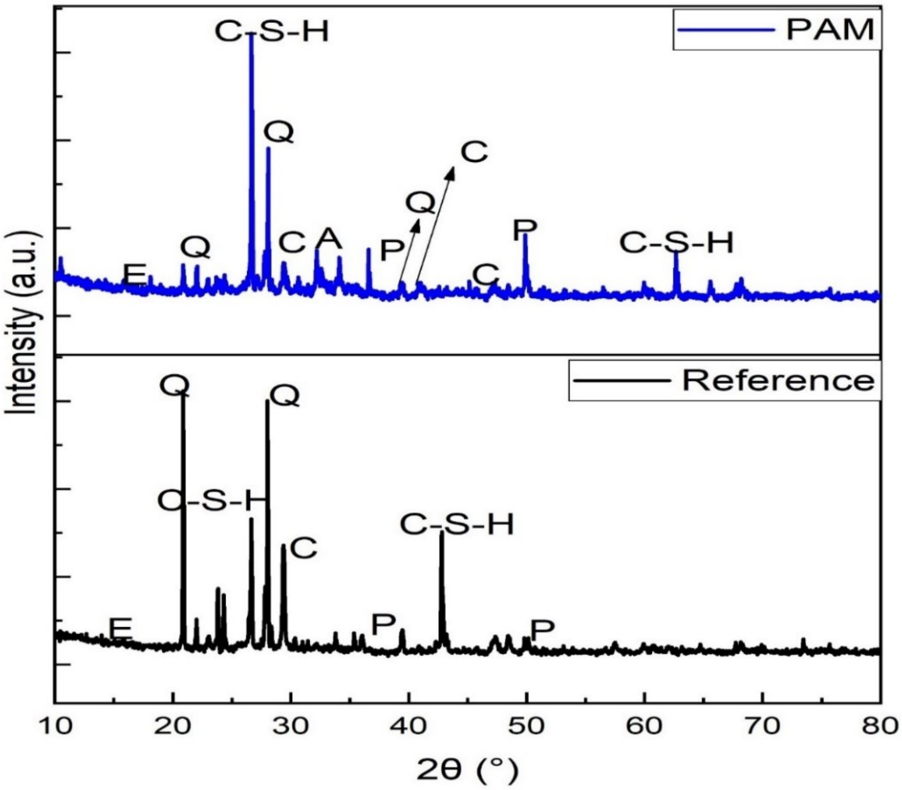
Figure 4. FTIR Spectra of (a) Water cured samples (b) Air cured samples

3.3.2 XRD

Figures 5(a) and 5(b) show the variation in XRD spectra of water- and air-cured samples, respectively. According to the figures, all four samples in both curing conditions consist of five major components: vizCalcium sulphoaluminate (E - Ettringite), Hydrogel (C-S-H), Calcium hydroxide (P – Portlandite), Calcium Carbonate (C – Calcite) and Silicon dioxide (Q – Quartz) in crystalline phases. In addition, other components are also present, but in trace quantities. In air-cured samples, another crystalline phase observed only in the PAM replaced mix is Aragonite, which is another form of Calcium Carbonate. In the case of air curing, the sample with PAM replacement shows an increase in the intensity of the C-S-H hydrogel peak. This denotes that PAM replacement tends to increase hydration under air curing conditions. In both water- and air-cured conditions, samples with PAM replacement show an increase in calcium carbonate components in various forms. An earlier study by Zhi et al. [46], which observed that PAM addition to cement aids in its carbonation, correlates with this result. These calcite components fill the pores, reducing the mix's porosity and increasing its overall strength. Thus, from the XRD results, it was evident that the usage of PAM as a partial cement replacement enhanced the carbonation and self-curing ability of the pervious concrete.



(a)



(b)

Figure 5. XRD Spectra of (a) Water cured samples (b) Air cured samples

3.3.3 SEM/EDAX

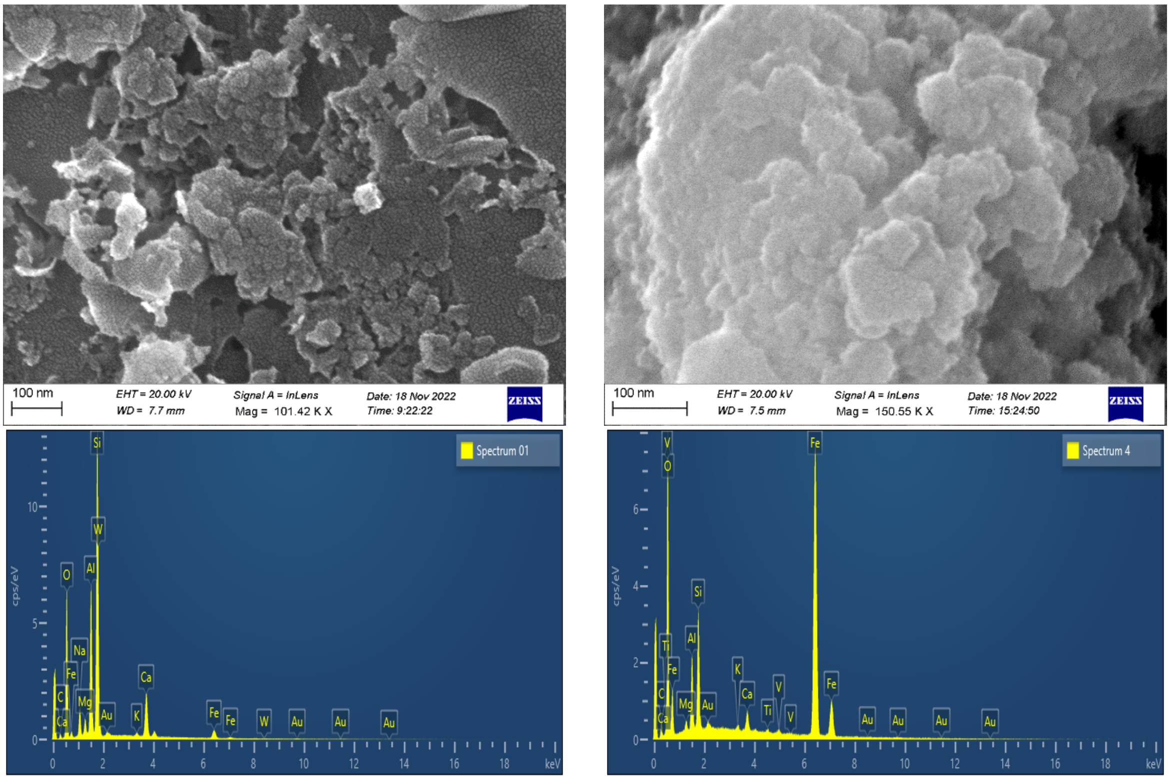
Figures 6 and 7 contrast the SEM/EDAX images of samples with and without PAM replacement in water- and air-cured conditions, respectively. The Figures reveal that the EDAX spectra of all four samples show minimal variation, regardless of the replacement or curing condition. This is due to the lower percentage of replacement. Similarly, SEM images show minimal changes in the microstructure of both the reference and PAM-replaced mix. Both reference and PAM-replaced mixes contain agglomerated patches, which represent calcite and hydrogel. But in the case of PAM, the agglomeration is high in comparison to the reference mix denoting the calcite and hydrogel components, as observed in XRD studies. Ettringite is indicated by the presence of very thin and minute needle structures. SEM images yield little inference other than these minor changes.

SEM images of air-cured samples, as depicted in Figure 7, denote the presence of angular, flaky, and spherical particles. In both cases, we observe little striking variation, except for the shape. This indicates that, with a lower replacement percentage and physical replacement, the internal structure of the mix does not exhibit significant variation. However, further analyses are necessary to confirm this finding.

3.4 Water Purification analysis

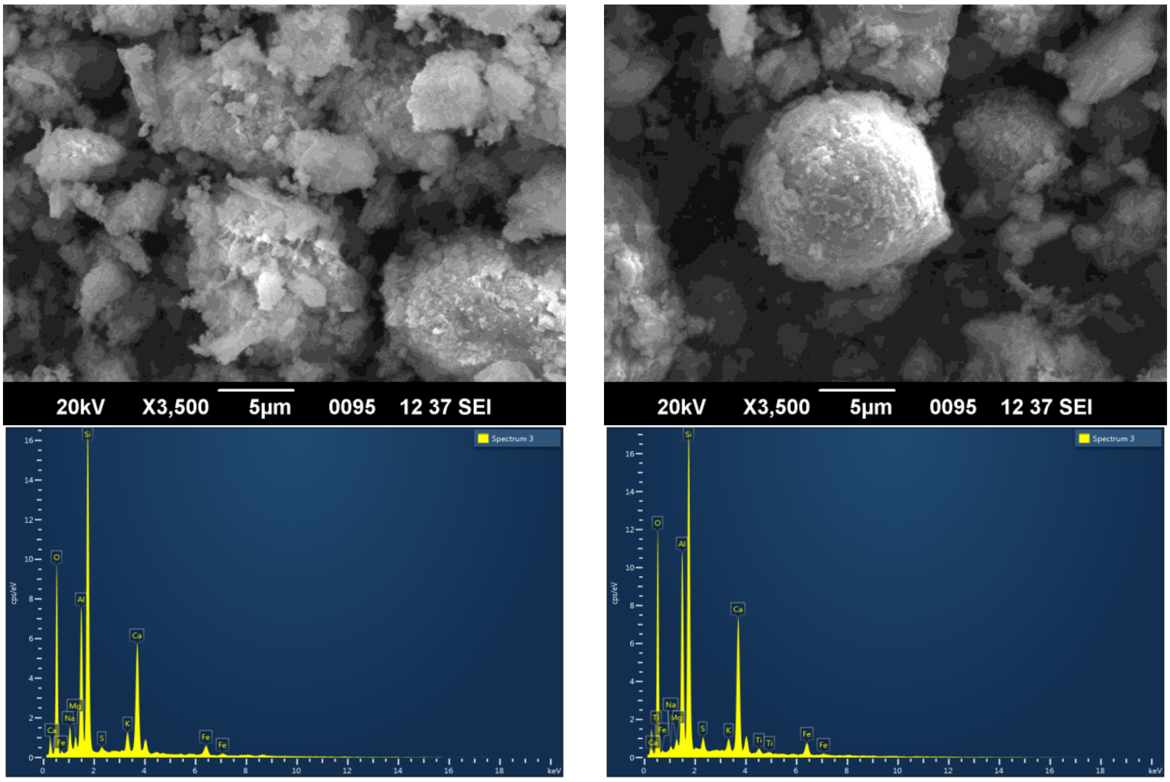
The study of wastewater characteristics that leached from the reference pervious concrete specimen itself shows a big drop in the pollutant parameters listed in Table 4. Figure 8 shows how the removal efficiency of different wastewater parameters changes with the percentage of PAM. Pervious concrete usually eradicates contaminants by means of two different mechanisms, namely microbial degradation and mechanical retention [47]. Mechanical retention is achieved by the chelating property of cement particles. The pores in pervious concrete, on the other hand, hold microbes, which makes the water treatment process more effective. In typical wastewater treatment plants, TSS is removed through filtration. Retention and various other chemical treatments achieve COD reductions, while microbial activity primarily drives BOD and TOC reductions. Chemical and biological processes remove the other two contaminants, TP and TN. According to the study, an increase in PAM content significantly reduces pollution parameters. The maximum removal is observed in 2% replacement. While additional replacement could potentially boost purification efficiency, we discourage it as it could compromise the mix's mechanical performance.

This study shows that the reference mix significantly reduces TSS removal compared to other PAM-replaced mixes. This is due to the enormous porosity of the mix in comparison to PAM-replaced mixes. The pores present in the reference mix have a larger size than TSS particles. Thus, the reference mix shows a removal efficiency of only 9.6% with respect to TSS particles. However, an increase in PAM content fills the voids amongst coarse aggregates, enhancing its ability to retain TSS particles passing through it. Thus, TSS in the resultant leachate is lower than its initial concentration. With the increase in PAM content, there is a significant blockage in pores, thereby increasing TSS removal.



(a) **(b)**

Figure 6. SEM/EDAX of water cured (a) Reference (b) PAM replaced mix



(a) **(b)**

Figure 7. SEM/EDAX of air cured (a) Reference (b) PAM replaced mix

In comparison to all the parameters, TP shows a higher removal rate of 82.5% when the percentage replacement is 2%. TN demonstrates a maximum efficiency of 71.9%, surpassing other parameters, as depicted in Figure. Removal of TP and TN takes place both by mechanical retention as well as microbial degradation remove TP and TN from pervious concrete. In addition, according to reports from earlier studies, the amine groups of the polymer have the ability to adsorb phosphate ions, thereby increasing the overall removal efficiency of phosphate ions [48]. Nitrate also follows a similar mechanism of mechanical retention and microbial degradation with respect to removal. Though in both cases, with the reduction in porosity, there can be a reduction in microbial degradation. Mechanical retentive ability and the presence of polyacrylamide balance this backlog, thereby enhancing the removal efficiency of the mix with respect to phosphate and nitrate.

The parameters COD, BOD, and TOC have almost comparable reduction efficiency, with the maximum being 67.6%, 65.4%, and 64.5%, respectively, for 2% replacement. This reduction in all three parameters can be explained by mechanical retention as well as microbial degradation, as mentioned earlier. While the increase in PAM ensures an enhancement in retention, signifying an increase in the rate of COD removal in comparison to BOD and TOC. This also explains the lower COD removal in the reference pervious concrete specimen compared to the PAM-replaced mix. The addition of PAM enhances the possibility of chelating inorganic contaminants, while simultaneously reducing porosity. This reduction in porosity reduces microbial proliferation, resulting in a higher rate of COD reduction compared to BOD and TOC, as shown in Figure. On the other hand, despite the reduction in pores, there is an enhancement in BOD and TOC removal. This also indicates the chelating ability of amine functional groups in PAM polymers, which retain both organic and inorganic contaminants. The increase in retention time is another significant factor that aids in the reduction of these parameters. With the increase in PAM, there is a reduction in the infiltration rate of water through every sample. This lessening of infiltration increases the time that wastewater is in contact with different types of pervious concrete, which mechanically retains a lot of the contaminants. However, more research is necessary to confirm the combined efficiency of wastewater treatment using PAM instead of Pervious concrete mixes, as there are not many studies available elsewhere in this area.

Table 4. Characteristics of Wastewater post passing through Pervious Concrete

S. No.	Replacement (%)	TSS (mg/l)	TP (mg/l)	TN (mg/l)	BOD (mg/l)	TOC (mg/l)	COD (mg/l)
1	0	104	35	17	288.63	170	558
2	0.5	77	30	14.5	225	136.9	400
3	1	69	21	11	200	117	346
4	1.5	57	17.7	9.5	180.07	105	307
5	2	51	15	6.5	160	93	270

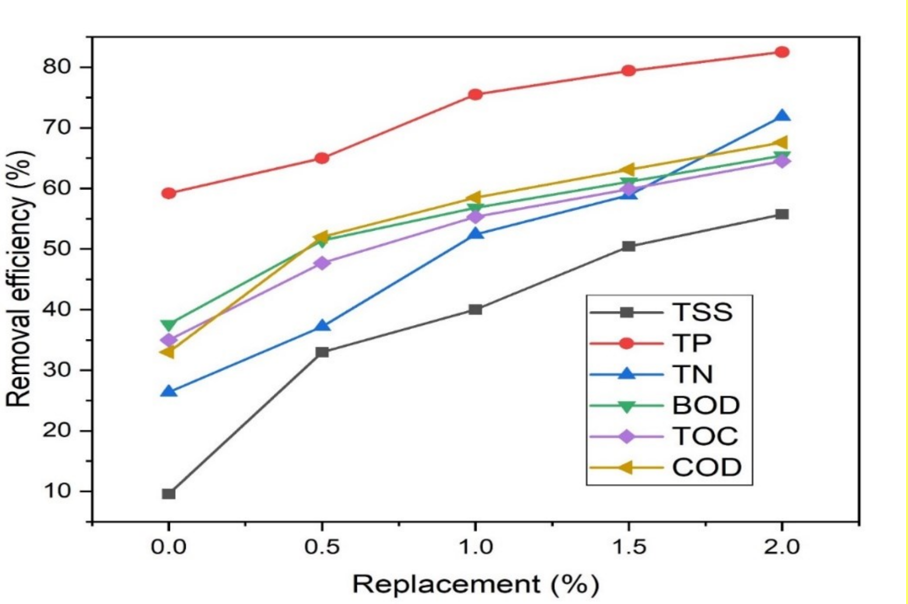


Figure 8. Removal efficiency Vs Percentage Replacement using PAM

4 Conclusion

Water-soluble polymers are used to partially replace cement in pervious concrete. Polyacrylamide significantly alters the engineering properties of concrete. Polymer replacement seemingly enhances the workability and converts the medium workable mix to a highly workable one. This is due to the water-soluble nature of the polymer, which enhances the fluidity of the mix. The same lubricating effect of the polymer reduces the fresh and hardened density of the mix. Furthermore, an increase in percentage replacement significantly reduces the specimens' porosity, water absorption, and infiltration capacity. Furthermore, the dispersive nature of the polymer explains the increase in resistance to abrasion as the PAM percentage increases.

The results of compressive strength analysis under water curing conditions indicate that when PAM is replaced for up to 0.5%, it increases in strength. Further enhancement decreases strength. Increased Porosity up to 1% does not significantly impact compressive strength. The reduction in binder content primarily explains this phenomenon. This study demonstrates that compressive strength not only depends on physical factors like density and porosity, but also on a chemical factor, namely binder content. To some extent, a reduction in binder content does not affect compressive strength. However, further reduction in the binder content tends to reduce the compressive strength despite the increase in porosity of the mix.

It is also observed that PAM serves as a retarder, thereby reducing the mechanical efficiency of the mix during the initial curing period. In the case of atmospheric curing, it is inferred that PAM serves as a self-curing agent. Micromechanical analysis by XRD further confirms these results, indicating the enhanced hydration of the mix through variations in intensity and peaks. FTIR and SEM/EDAX results show no significant variation owing to the lower replacement percentage.

Water purification analysis results reveal that inculcation of PAM into pervious concrete mix enhances the water purification ability significantly. With respect to all parameters, 2% replacement showed the maximum reduction efficiency. Of all the parameters considered, TP showed the maximum removal, whereas TSS showed the minimum one. The primary mechanisms involved in water purification are mechanical retention and microbial degradation. PAM replacement improves the samples' mechanical retention ability.

Thus, on a concluding note, it can be said that PAM serves as a potential alternate for cement in pervious concrete when used in a limited quantity. While a 2% replacement is optimal for water purification, we limit the replacement percentage to 0.5% or 1% to avoid compromising other pervious concrete efficiencies. Hence, according to ACI reports, PAM-replaced concrete serves as a cleaner alternative for its use in sludge drying beds, considering its water purification ability as a characteristic parameter.

CRediT author contribution

M Abhinaya: Methodology, Investigation, Writing – Original draft

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N. Sivakumar: Methodology, Writing – Review & Editing, Validation

Declaration of Competing Interests

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