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Feasibility Studies on Enhancement of Mechanical and Water Purification Properties of Pervious Concrete Using Granite Dust as Partial Cement Replacer

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Abstract

Usage of pervious concrete in pavements, roof tops and other such applications has increased recently. This type of concrete aids in infiltration of excessive run-off in an ecofriendly manner. In this study, improvement of pervious concrete properties using industrial waste granite dust (GD) as partial cement replacement is analysed. Percentage of replacements so considered is in range of 0.5 – 2% and compared with reference mix properties. Results of the analysis show that replacement using GD for upto 1% increases the strength of the sample. Therefore, in the mix with 1% GD, a maximum strength of 13.5 MPa is observed which is 41% higher than that of mix without replacement. While GD replacement enhances the density, reduction in porosity, infiltration capacity, and water absorption is observed consequently. This variation in property is reasoned by the micro-filling effect of GD. In addition, dried powder samples are analysed using SEM/EDAX, FTIR, and XRD. Further analysis of water treatment ability of the pervious concrete specimens considering six parameters namely TSS, COD, BOD, TOC, TP, and TN show that GD replacement can potentially increase the pollutant removal ability of the mix than that of reference mix with maximum removal achieved for TP (77.9%) in sample with 2% replacement.

1. Introduction

With the increased development in technology, a rapid increase in rate of industrialization and urbanization is observed, which causes pollution followed by disruption in ecosystem. Of all industries, cement industry is the third major global contributor to Carbon dioxide (CO_2) pollution worldwide. With concrete being the second most consumed material globally, an exponential increase in cement production and utilization is observed, triggering more pollution due to the cement industry. A study by Fayomi et al., (2019) [1] confirms that 1 ton of cement production results in 0.5-0.9 tonne of CO_2 emission to the atmosphere. Further, the same study shows that cement industry is energy dependent that exploits non-renewable energy resources namely fossil fuels for various production processes. With these reasons serving as provocation, the need for Supplementary cementitious materials (SCMs) has increased these days.

On the other hand, with the increase in untimely precipitation in recent times an increase in surface run-off is observed in urban areas. This results in flash flooding and excessive erosion that further contaminates other water resources [2]. Thus, for the reduction in run-off, concrete with increased porosity is used for pavements, parking lots, roof tops and other places that are susceptible to excessive run-off. Such type of concrete is termed as pervious concrete which is made only using cement and coarse aggregates thereby enhancing its porosity [3]. Usage of Pervious concrete for pavements not only reduces flash flooding damages but also enhances pollutant removal from surface run-off, reduces urban heat island effect, improves vehicular noise resistance and skid resistance etc., Presence of pores in pervious concrete enhances the growth of roadside trees and shrubs [4]. Thus, Pervious concrete serves as a sustainable, eco-friendly pavement system in comparison to other impervious pavements.

Despite all these benefits usage of pervious concrete is not pronounced that much owing to its reduced strength in comparison to normal pavement structures. To attain the nominal infiltration capacity of 1.4 to 12.2 mm/s and porosity of 15 to 35% in pervious concrete fine aggregate percentage in pervious concrete specimens is reduced that results in strength in the range of 2.8 to 28 MPa. This strength is lower than the strength of usual concrete with fine aggregate [5]. Thus, various techniques are adapted to enhance its strength requirements keeping in account of its porosity [6]. One such technique is partial replacement of cement using various SCMs such as crushed stone dust, fly ash, waste rubber tires, Silica fume etc., for improvisation of mechanical properties in pervious concrete [7-9]. From previous studies it is to be noted that various industrial wastes have the potential to enhance pervious concrete performance when used as an additive or replacement for cement.

For instance, Gao et al., (2021) [10] had studied effects of using silica fume and fine aggregate as partial replacement for cement and coarse aggregate respectively. Results of the study show that replacement of raw materials using Silica fume and fine aggregate shows better improvement in properties such as flexural strength, abrasion resistance, and compressive strength as well. In addition, it also reveals that replacement using these materials enhances the resistance of the pervious concrete mix to acid attack. Another study made by Kim et al., (2016) [11] shows effects of using fly ash, fibres, and tire chips in pervious concrete. Results of load bearing capacity analysis show that inclusion of fibres improves the strength whereas inclusion of other two materials reduce the same. With respect to hydraulic characteristics, tire chips clog the pores of pervious concrete whereas fibres and fly ash inculcation improves the same facilitating further studies on storm water drainage.

Another primary advantage of pervious concrete is its ability to remove pollutants from storm water. This ability aids in reduction of contaminant load in surface run-off that percolates the porous pavement thereby reducing the ground water pollution. For instance, Park and Tia, (2004) [12] had studied the water treatment ability of pervious samples that consist of silica fume and fly ash. Results show that pervious concrete can reduce phosphorus and nitrogen contaminant. The study reasons that this reduction in pollutant content is because of the micro-organisms that is present in the pores of pervious concrete. Measure of Dissolved Oxygen content of the waste water indicates the activity of microbes that is present in pervious concrete pores. Another study by Lee et al., (2013) [13] has analysed the pervious concrete's performance in reducing acidity of dilute sulphuric acid (simulating acid rain), oil content in waste lubricating oil and salinity of sea water. Results reveal that pervious concrete possess the ability to remove all the three contaminants upto considerable percentage. Thus, care should be taken that usage of SCMs should focus the enhancement of water purification ability without compromising the corresponding hydraulic, mechanical and durability performance of pervious concrete.

One such commonly used SCM is inorganic, non-biodegradable solid waste granite dust (GD). Earlier studies had shown that, reutilization of GD is performed by its usage as partial cement replacer in concrete. A review study carried out by Danish et al., (2021) [14] analyses various studies that has explained the effects of replacing cement with GD in concrete, mortar etc., Inferences from the study reveal that usage of granite dust and marble dust as partial cement replacers seems beneficial in terms of enhancement in mechanical and other properties of cement. Few other research studies reveal that percentage replacement of cement or fine aggregate using GD enhances compressive strength, corrosion resistance, flexural and tensile strengths [15-16].

Despite all these benefits usage of GD in pervious concrete is not that much pronounced. This is owing to the fact as few studies reveal that replacement using GD enhances the density of the concrete [17]. This is reasoned by filler property of GD that tend to reduce the porosity which in turn lowers infiltration ability of the specimen. On the other hand, very few studies had explored the water purification performance of granite dust. For instance, Ahmed et al., (2020) [18] in his study had explored the efficiency of using granite waste in its raw and fired form in conjunction with fungi named *Aspergillus niger* for adsorption of phosphate ions. Results of the study reveal that granite waste serve as a potential adsorbent for removal of phosphate ions in both the cases. Another study by Kadhim, (2012) [19] shows that granite particles can adsorb various types of dye efficiently. Further studies are needed in detail for the exploration of adsorption efficiency of granite particles. Considering all the basic advantages, this study considers reutilization of GD as partial replacer to cement in pervious concrete.

1.1 Objectives

The current study examines the effects of GD replacement in Pervious Concrete. This ensures the granite industry waste valorisation and improvement of pervious concrete property in an environmentally efficient manner. As there are possibilities that the minute granite particles seemingly reduce the infiltration capacity of the mix, percentage of granite dust so chosen for replacement is limited to 0.5 to 2% by weight of binder. The properties considered include strength, density, water absorption efficiency, infiltration capacity and porosity of pervious concrete samples. FTIR, XRD and SEM/EDAX are used for microstructural analysis. Finally, wastewater treatment ability variation with respect to different percentages of granite dust in pervious concrete samples is investigated considering parameters namely Total Suspended Solids (TSS), Biochemical Oxygen Demand (BOD), Total Nitrate (TN), Total Organic Carbon (TOC), Total Phosphate (TP), and Chemical Oxygen Demand (COD).

2. Experimental Program

2.1 Preliminary Analysis of Raw Materials

Pervious Concrete primarily consists of coarse aggregates and binder mixed with the aid of water. The presence of fine aggregate depends upon the strength and porosity requirement. Usage of chemical admixture is preferred mostly but is optional. In this study, 10% of M-sand is used as fine aggregate. Fly ash based Pozzolana Portland cement (PPC) procured commercially is used as binder and is tested following procedures from IS 4031 Parts 4 and 5: 1988 [20-21] and are found to be in line with range as specified in IS 1489 (Part 1): 1991 standards [22]. Coarse aggregates used in this study are blue granite stones procured commercially with a uniform size of 12 mm. Both fine and coarse aggregates are tested in accordance to IS 2386 (Part 3 & 4): 1963 [23-24] and are found to be in line with the specifications confirming to IS 383:1970 standards [25]. No admixtures are used in this study to analyse the complete effect of GD in pervious concrete.

Granite dust (GD) required for replacement is collected from an industry in Madurai city, Tamil Nādu, India. The raw material so obtained is grinded to get fine powder of size less than or equal to 75μ for further usage. The as procured GD is characterised by X-ray diffraction (XRD) analysis to identify its chemical components. Fig. S1 shows XRD results of GD. From the results, it can be identified that Silica (SiO_2) forms the major component of GD particles. GD on a whole is composed of various forms of silica namely Albite (Sodium aluminosilicate – $NaAlSi_3O_8$), Biotite (Phyllosilicate mineral combined with Potassium, Magnesium, Iron or Aluminium) and Quartz (SiO_2). While Quartz forms the major component of GD, traces of Maghemite (Fe_2O_3) is also observed. In addition, from the intensity of peaks it is also inferred Quartz mineral can exist in combination with other forms of silicate minerals namely Orthoclase (Potash Feldspar – $KalSi_3O_8$), Actinolite ($Ca_2(Mg\ Fe)_5Si_8O_{22}(OH)_2$) analogous to earlier observations [26-27].

2.2 Mix Ratio and Casting

Usual water-cement ratio (w/c) for pervious concrete ranges from 0.26 to 0.40 as per the previous literatures. In this study, the standard w/c, and a binder-aggregate ratio of 0.40 and 1:4 respectively is adapted for all the mixes. A quantity of 10% by weight of binder is taken as standard M-Sand quantity as mentioned earlier. Since there is no standard mixing or analysis procedure available, standards used for conventional concrete is followed in the study. 100mm cubic samples are casted and used for mechanical property analysis. Since the size of aggregate is less than 20mm, cubes of size 100mm is adapted as per IS 516:2018 [28] standard. Cubes of 5 different mix ratios are prepared and given Sample ID of 1, 2A, 2B, 2C and 2D for mixes with replacement percentages 0%, 0.5%, 1%, 1.5% and 2% respectively. Raw materials are dry mixed initially followed by wet mixing. Table vibrator is used for compaction. Post compaction the sample is left undisturbed for 24 hours and is cured with water in room temperature.

Infiltration capacity of pervious concrete samples is determined using infiltration ring of 12 inch in pavement system. Since it was an in-field test, a modified test is specified in ASTM c 1701 M-09 [29]. In this study, modified test is adapted for measurement of infiltration capacity. Cylindrical specimens of size 100mm X 200mm are casted using PVC pipe moulds of standard diameter as represented in Fig. S2. PVC moulds used are of height 220mm to maintain the standard head required for infiltration capacity analysis. Pipe moulds are used to avoid seepage of water through the sides. The casted samples are immersed in tap water for seven days and are tested adapting the procedure specified in Haselbach et al., (2017) [30]. Water Purification capacity of the samples is analysed using the same cylindrical moulds.

2.3 Analysis

Post casting and curing compressive strength on cubic samples are analysed on 7, 14 and 28 days of using a Universal Testing machine (UTM – Hitech India equipments/TVE-CN-600 model). The tests are performed in triplicates to ensure uniformity as entitled in IS 516:2018.

Procedure from ASTM c 1754 (2012) [31] is adapted for measurement of density and porosity. Formula (1) adapted from ASTM standard is used for calculating porosity where M_s and M_d represent submerged and dry masses of sample respectively, ρ_w and V represents density of water and volume of specimen respectively.

$$Porosity = 1 - \frac{(M_d - M_s)}{\rho_w V} \quad (1)$$

Further water absorption of pervious concrete mixes is measured adapting the procedure from Shah and Pitroda, (2014) [32]. Abrasion resistance of pervious concrete mix is analysed using Pneumatic sand blasting equipment as specified in IS 9284:1979 [33]. All the four tests viz, density, porosity, water absorption and abrasion resistance are performed after 28 days of curing.

Micromechanical analysis of samples is carried out using Scanning Electron Microscopy with Energy dispersive X-ray spectroscopy (SEM/EDX – FE-SEM – EVO 18, ZEISS, UK), Fourier Transform Infrared Spectroscopy (FTIR – Perkin Elmer – L1600300, Liantrisant UK), X-ray diffraction (XRD – Powder XRD, Smartlab SE X-Ray, Rigaku, Japan). Powdered cement samples are collected from cubes after 28^{th} day compressive strength analysis.

Infiltration capacity of samples is analysed as per the procedure in ASTM c 1701 M-09 [29] as mentioned earlier. The samples are pre-wetted using the same volume of water that is to be considered for testing to ensure that the tests are carried out in saturated condition. Water is made to flow through the sample. A small head of less than 10mm is maintained and the time of flow of sample is recorded. Infiltration capacity of the sample is calculated using formula (2).

$$Infiltration\ Capacity = \frac{4V_w}{D^2 \Pi t} \quad (2)$$

Here V_w denotes volume of water used for analysis, D denotes diameter of the sample and t denotes time taken for infiltration.

For analysis of water purification capacity sewage collected from Treatment plant in SSN College of Engineering, Tamil Nadu, India is used. Waste water so obtained is characterised considering various parameters namely TSS, COD, BOD, TOC, TP and TN. In which, TSS, TP and TN of the samples are determined using DR 9000 reactor from Hach, COD and TOC are analysed using DRB 200 reactor from Hach and BOD of the sample is determined by Respirometric method using BODTrak™II apparatus. As per usual practise a five-day BOD measured at a standard temperature of 20ºC is considered as BOD value in this study. Cylindrical samples of 200mm depth are used for wastewater purification analysis simulating usual run-off pattern. Tests are carried out for three consecutive days collecting fresh samples of untreated raw sewage water each day. Raw sewage samples are considered simulating the run-off treatment load considered for usual design period of pavement which is over 5 years minimum. The average characteristics of untreated raw sewage sample so collected is showed in Table 1. The values mentioned are average sewage characteristics measured for all the three days with an upper and lower limit of variation being 50 ppm.

Table 1 *Raw water characterisation*

S. No.	Parameters	Values (ppm)
1	TSS	115
2	COD	833
3	BOD	462.63
4	TOC	261.67
5	TP	85.8
6	TN	23.1

3. Results and Discussions

3.1 Microstructural Analysis

Fig. S3 shows the FTIR results of 28 days cured samples. Four distinct peaks are observed in FTIR spectrum of both the samples. The peaks over 3500 cm^{-1} usually denotes hydroxyl groups. Stretching peaks in 3614 cm^{-1} and 3601 cm^{-1} respectively in unmodified and GD modified pervious concrete mix attributes to the presence of hydroxyl groups. This hydroxyl is a characteristic functional group of $Ca(OH)_2$ (Portlandite) an important hydration product. Further, vibrations in the range of 700 – 1500 cm^{-1} attributes to Calcium silicate and Calcium Aluminate hydrogels (C-S-H and C-S-A hydrogels). As this peak range attributes to Si-O, Al-O and C-H bonds the presence of stretching vibrations in this range denotes the presence of hydrogels. Other than very slight shifts in certain peaks and corresponding stretches the overall FTIR spectrum of both the samples are same. This denotes the fact that not much chemical reactions take place owing to the inertness of GD as well as low quantity of replacement.

Fig. 1 shows the XRD results of samples with and without GD replacement. From fig. it can be inferred that other than an increase in intensity of quartz (Silica (SiO_2)) not much change is observed in hydration of cement. From XRD graphs it can be observed that both the mixes consist of various crystalline phases with five being the major components. The main components include C-S-H hydrogel, Portlandite ($Ca(OH)_2$), Quartz, Ettringite (Calcium Sulphoaluminate), and Calcite ($CaCO_3$). Though the hydration products remain the same, from results of XRD it can be observed that quantity of Silica is slightly higher in mix with GD replacement than in mix without replacement. Since GD is composed of Silica and various forms of silicates an increase in quantity of Silica is observed in the mix. This increase in silica reasons the strength gaining attribute of GD replaced mix. The variation is not too pronounced owing to the low percentage of replacement [15].

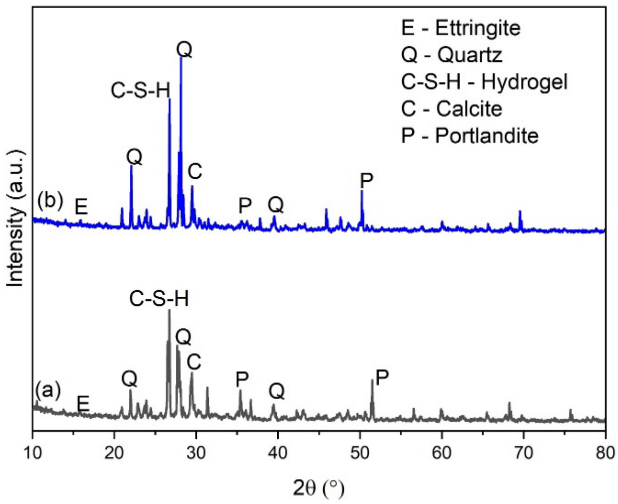
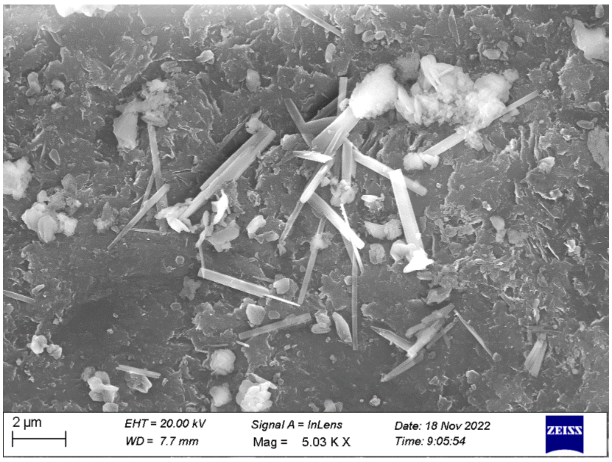
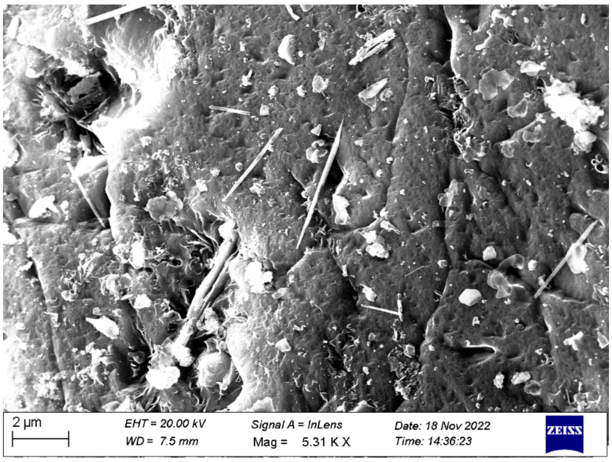


Fig. 1 *XRD results (a) Reference mix (b) GD replaced mix*

SEM/EDX results shown in Fig. 2 and Fig. 3 respectively are in line with the XRD results. Observations from Fig. 2 denotes that replacement using GD results in densification of cement microstructure. While the reference mix is composed of agglomerated pores and ettringite needles with smooth surface SEM images of GD replaced mix denotes the enhancement in ettringite needle's structure. In addition, GD replacement tends to give rough structure that enhances the strength of the mix which is discussed further in section 3.2. Likewise, from EDX results observed in Fig. 3 it can be inferred that replacement using GD enhances the percentage silica content of the mix confirming to results of XRD. This enhancement of silica percentage reasons the significant strength enhancement of GD replaced mix.

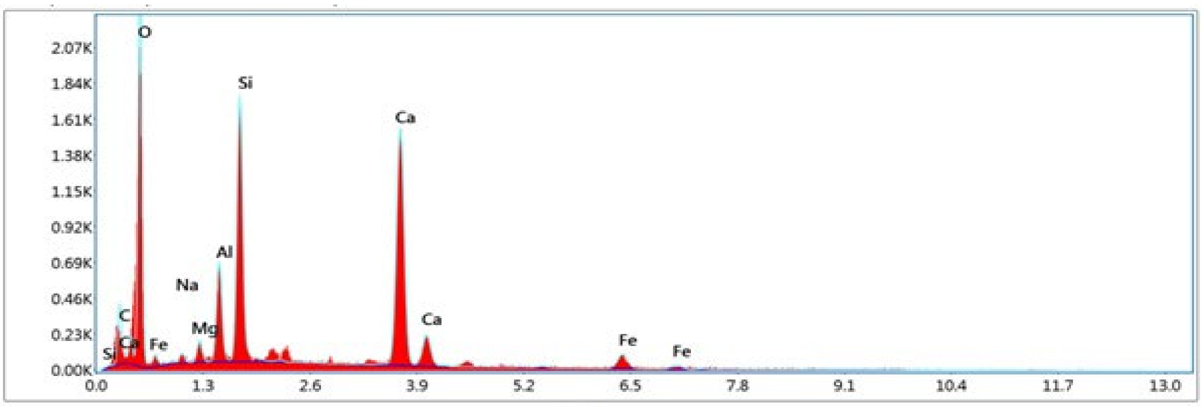


(a)

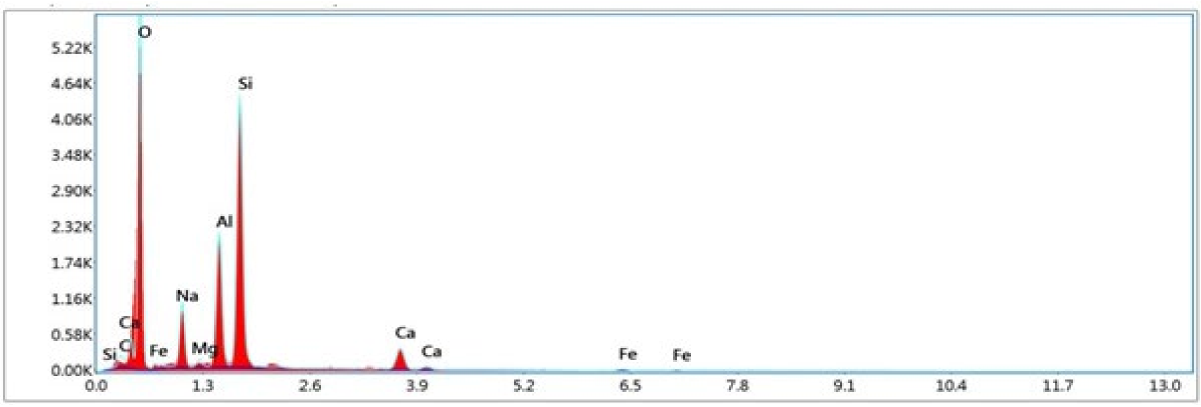


(b)

Fig. 2 *SEM results of (a) Reference mix; (b) GD replaced mix*



(a)



(b)

Fig. 3 *EDX results of (a) Reference mix; (b) GD replaced mix*

3.2 Compressive Strength

Table 2 depicts results of various hardened property tests. From table it can be identified that though replacement using GD enhances the compressive strength and density, it results in reduction of porosity, infiltration capacity and water absorption of the samples.

Results of compressive strength analysis shows that increase in age of curing tends to increase the strength of the sample significantly following the usual pattern despite the usage of GD. Observations from results denote that replacement of GD for upto 1% tend to enhance the strength of the mix on a whole. Though further increase reduces the strength, it is not lower than that of the reference mix. This variation in strength enhancement pattern is because GD on replacement tends to fill the micro voids amongst the coarse aggregates thereby aiding in reduction of air voids. This reduction in air voids improves the strength of resultant mix [34]. Thus, GD on replacement increases the strength of pervious concrete because of its micro filling effect analogous to the observations in a study by Elmoaty (2013) [15]. Despite this ability of GD particles, further increase in GD over 1% reduces the strength of the mix. This is owing to the reduction in binder density around the aggregates as excess replacement reduces the thickness of binder coating in the concrete mix that results in reduction of the strength. Thus, replacement using GD for upto 1% by weight of cement improves the mix strength by 41% than that of mix without replacement. Overall higher strength obtained is 13.5MPa for 1% replacement after 28 days of curing. Further increase though reduces the strength, maximum strength after 2% replacement is 9.39 MPa which is almost 15% higher than reference. Further GD replacement over 2% may reduce the strength of the specimens drastically.

3.3 Density

Table 2 depicts that increase in percentage replacement tends to increase hardened density linearly. This result follows a directly proportional relationship with compressive strength results upto 1% replacement as shown in Fig. S4. This is reasoned by the micro filling effect GD particles that enhances the density thereby reducing air voids. This reduction in air voids aids in enhancement of compressive strength. However, on further increase in GD volume compressive strength is reduced despite the increase in density thus giving an inversely proportional relationship. This emphasizes the fact discussed earlier that over a certain percentage replacement, binder volume around the aggregate gets reduced than usual that reduces the strength of the sample irrespective of variation in density.

3.4 Water Absorption

Observations from Table 2 shows that increase in GD percentage decreases the water absorption of the samples significantly. Fig. S5 depicts the density and water absorption variation with replacement percentage. Inference from the Fig. S5 denotes that increase in density reduces the water absorption of the mixes significantly. This is because of the reduction in pore percentage that can absorb water. Thus, it is inferred that density and water absorption of pervious concrete mix has an inverse relationship when cement is being replaced with GD [35].

3.5 Porosity

From Table 2 it can be inferred that with replacement of cement using GD, a significant reduction in porosity is observed. This is reasoned by the filler effect of fine GD particles. The results also signify the inverse relationship of density with porosity as well as direct relationship of water absorption with porosity as depicted in Fig. S6 and Fig. S7 respectively. That is, it is inferred from Fig. S6 that there is a significant reduction in porosity with increase in density. On the contrary, water absorption decreases as porosity decreases. Though the percentage of reduction in water absorption and porosity varies, both the parameters show a characteristic reduction with increase in replacement percentage as observed in Figure S7. These occur because an increase in percentage replacement using GD, tends to fill the air voids which results in reduction in porosity of the sample. This porosity reduction correspondingly aids in reduction of water absorption capacity of the sample in contrast to the increase in density. Porosity reduction also tends to enhance the compressive strength of sample for upto 1% replacement. Further an increase in GD replacement though leads for pore content reduction, does not enhance the strength of the mix as observed in Fig. S8. This on a whole can be reasoned by reduction in overall binder content required to bind the aggregate particles thereby thinning the cement cover over the aggregate resulting in reduction in compressive strength as discussed earlier.

3.6 Abrasion Resistance

Results of percentage abrasion loss for modified pervious concrete samples as observed in Table 2 denotes increase in percentage replacement using GD increases the abrasion resistance of the mix significantly. Earlier studies show that abrasion loss is directly proportional to porosity [36]. It is observed that increase in GD tends to reduce porosity of pervious concrete. This reduction in porosity results in dense packing of pervious concrete mix thereby increasing its abrasion resistance. Thus, it is inferred that replacement of pervious concrete mix using GD tends to enhance the abrasion resistance of pervious concrete.

3.7 Infiltration Capacity

Table 2 shows the infiltration capacity variation with percentage replacement using GD. Observations from table denotes that increase in GD there reduces the infiltration capacity significantly. This result is in line with variation in porosity as observed in Fig. S9. Results denote that the porosity of reference mix is 13.5% which is slightly lower than porosity specified in standards. This is owing to usage of a little percentage of fine aggregate. Despite this reduction, infiltration capacity of the sample is within the usual limits stating the fact that infiltration capacity is not the function of porosity alone. Fig. 4 illustrates that infiltration capacity reduces significantly with reduction in porosity of the mix. Though they both share a proportional relationship from the value of R^2 it can be inferred that the rate of reduction of infiltration capacity is not the same as rate of reduction in porosity. This clarifies that infiltration capacity not only depends on porosity but also depends on other factors with the primary one being pore connectivity [37]. Results denote that despite the reduction in porosity to a greater extent the reduction in infiltration capacity of all the samples is within limits as specified in ACI 522-R-10 standards [38]. Thus, with respect to infiltration capacity criteria all the mixes can be used for further analysis.

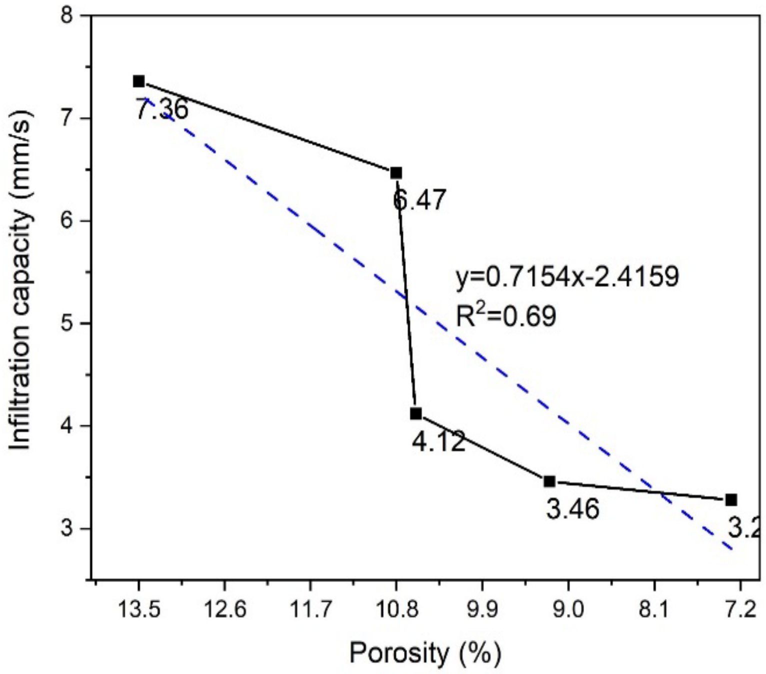


Fig. 4 *Variation in Infiltration capacity with porosity*

Table 2 *Hardened properties variation with GD replacement*

S. No.	Sample ID	Strength (MPa)			Density (kg/m³)	Water absorption capacity (%)	Porosity (%)	Abrasion loss (%)	Infiltration capacity (mm/s)
		7 days	14 days	28 days					
1	1	5.135	6	7.9	1907	8.023	13.5	0.32	7.36
2	2A	6.6	8.88	10.1	2059	8.014	10.8	0.28	6.47
3	2B	8.9	11.89	13.5	2140	7.991	10.6	0.18	4.12
4	2C	6.825	9.5	10.5	2156	7.746	9.2	0.1	3.46
5	2D	6.2	8	9.39	2199	6.867	7.3	0.05	3.28

3.8 Wastewater Purification Ability

Table 3 denotes the variation in wastewater treatment characteristics of the mixes. Observations from table denotes that replacement using GD enhances the wastewater treatment efficiency of pervious concrete with respect to all the parameters so considered. The values so obtained are average value of three trails as specified earlier. From table, it can be identified that reference pervious concrete mix also tends to enhance the wastewater quality. But it can also be inferred that the increase in GD replacement percentage, tends to enhance the removal efficiency of the specimens. Higher the replacement percentage higher the quantity of contaminants removed. Though further enhancement in GD may seemingly increase the water purification capacity, it is not encouraged as further increase creates a negative impact in hydraulic and mechanical performance of pervious concrete mix. Fig. 5 shows the percentage reduction variation of various parameters with respect to percentage replacement using GD.

Table 3 *Variation in waste water treatment capacity with respect to percentage replacement using GD*

S. No.	Sample ID	TSS (mg/l)	COD (mg/l)	BOD (mg/l)	TOC (mg/l)	TP (mg/l)	TN (mg/l)
1	1	104	558	288.63	170	35	17
2	2A	80	455	261	155	29	15
3	2B	72	411	236.31	141	21.4	12.3
4	2C	66	356	210.5	122.27	20	9.3
5	2D	55	333	195	115	19	7.5

3.8.1 TSS

The term Total suspended solids (TSS) demonstrate the presence of organic and inorganic solids of size greater than 2 microns in wastewater. Presence of TSS affects the physical characteristics of wastewater namely colour and turbidity making water unfit and uncomfortable for consumption purposes. TSS is mostly removed by filtration mechanism in usual treatment procedures. Results of TSS analysis on water leached from various specimens of pervious concrete denotes that increase in GD percentage in pervious concrete specimens tend to reduce the resultant TSS concentration in leachate as observed in Fig. S10. While in reference mix without any replacement shows only 9.6% of removal efficiency, replacement using even 0.5% of GD enhances the removal efficiency to 30.4%. Further increase in GD percentage tends to increase the removal efficiency of specimens. This denotes the reduction in pore size of the samples with replacement in comparison to pore size of reference sample. This result is in accordance with the porosity observations where it is inferred that replacement of cement using GD fills the pores thereby reducing the pore size and porosity. This reduction in pore size aids in filtration of TSS thereby increasing the purification efficiency of the specimens. However, further investigation is needed in this regard as efficiency of GD modified pervious concrete is wastewater treatment is not reported elsewhere.

3.8.2 COD, BOD and TSS

COD, BOD and TOC are primary parameters serving as an index for organic and inorganic pollutant concentration in wastewater. Observations from the analysis denotes that increase in GD percentage increases the treatment efficiency of the mixes with respect to COD, BOD and TOC as shown in Fig. 5. Inference from the figure denotes the fact that wastewater movement through pervious concrete aids in significant reduction of all the three parameters. Removal percentage of reference mix without replacement for COD, BOD and TOC are 33%, 37.6% and 35% respectively. Though replacement using GD enhances the removal efficiency of all the three parameters a characteristic variation is observed in the rate of enhancement of removal. While the replacement enhances COD removal in a higher rate, enhancement of BOD and TOC removal follows a comparatively low pace. This result denotes the presence of microorganisms in pervious concrete pores. Observations from earlier studies denote that water treatment in pervious concrete is achieved by mechanical adsorption as well as microbial degradation [39]. Pervious concrete with its enormous porosity practically serves as a reservoir for innumerable microorganisms that aids in degradation of contaminants. Thus, pervious concrete specimen without replacement consists of more microorganisms in comparison to other specimens with replacement as GD replacement reduces the porosity of the specimen on a whole. Reduction of COD involves the consumption of oxygen by both inorganic and organic contaminants in wastewater. Thus, COD removal efficiency of reference specimen is less in comparison to BOD and TOC removal efficiency of the same owing to the presence of higher microbial content.

On the parallel side, with the replacement of cement using GD though removal efficiency of all the three parameters shows an increasing trend a slight reduction in rate of reduction of BOD and TOC in comparison to COD. This is because, GD replacement reduces the porosity thereby reducing the space for microorganisms which is well reflected in rate of enhancement in BOD removal efficiency. On the other hand, the same reduction in porosity slows down the infiltration of wastewater through pervious concrete samples thereby enhancing the retention time of wastewater flowing through the pores. This enhancement of retention time increases the contact duration of contaminants in wastewater with reactive components of cement in pervious concrete specimen thereby aiding in increased removal efficiency of COD, BOD and TOC parameters.

3.8.3 TP and TN

Phosphates and Nitrates are two nutrients that are mandatory for living organisms for various purposes. Increase in phosphate and nitrate quantity in water aids growth of microbial organisms resulting in algal bloom followed by eutrophication thereby mandating the removal of TP and TN from wastewater.

Analysis of TP and TN concentration in water seeped through various pervious concrete specimens indicates the fact that all the specimens show better removal efficiency with respect to these two contaminants as observed in Fig. 5. The maximum removal is obtained in 2% replacement analogous to removal of other parameters as discussed earlier. Replacement using GD enhances the phosphate and nitrate removal efficiency of specimens. Earlier in a study by Ahmed et al., (2020) [18] granite waste in conjunction with *Aspergillus niger* finds its application as an adsorbent for phosphate ions removal from waste water. Results observed in current study is in line with the observation from earlier literature. TP and TN can be removed from waste water both by mechanical adsorption as well as microbial degradation. Despite the reduction in quantity of microbial proliferation after GD replacement as discussed earlier in section 3.6.2 there is a significant increase in both TN and TP removal. This is owing to the mechanical adsorption process. Replacement using GD reduces the infiltration pace of wastewater through the pervious concrete specimen. In addition, presence of contaminants enhances the viscosity of wastewater that further reduces the infiltration pace of the same thereby enhancing the contact time of contaminants with the pores. This enhancement in contact time results in reduction of TP and TN content in resulting water seeping from the specimens.

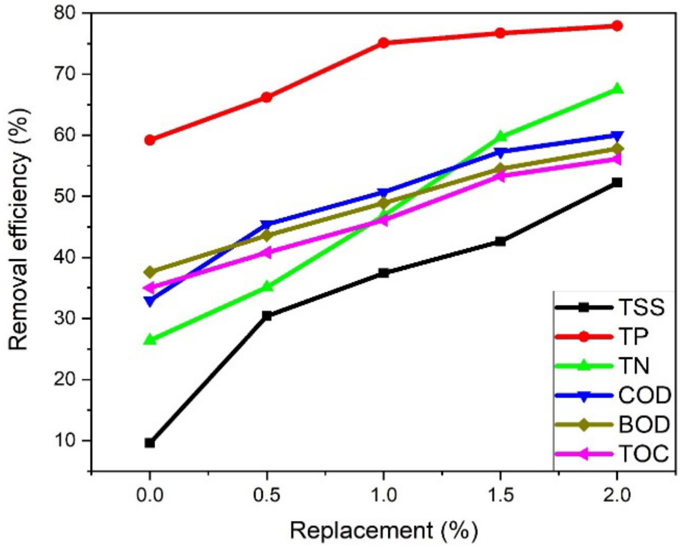


Fig. 5 *Removal efficiency variation with replacement percentage*

Results of triplicate study using wastewater of various other concentrations show that removal efficiency of all the contaminants with respect to percentage replacement using GD varies in accordance with initial concentration of sewage. But all the cases show similar variation pattern with respect to various pervious concrete specimen. That is, increase in GD percentage tends to enhance the removal of various contaminants from wastewater can be observed. Variation pattern of removal percentage of contaminant denotes that removal of contaminants from wastewater is mainly achieved by retention of contaminants in pores along with degradation using microbes present in pervious concrete pores.

4. Conclusion

The study mainly examines the effect of partially replacing cement in pervious concrete using granite dust and the major inferences are as follows:

1. GD replacement enhances the structural performance analysed in terms of compressive strength of the mix. For upto 1% replacement, the strength reaches a maximum of 13.5 MPa. On further increase of GD percentage, there is a reduction in strength which is reasoned by the reduction of binder thickness over the aggregates of pervious concrete. Thus 1% replacement is considered as optimum replacement percentage in terms of strength.
2. Replacement using GD increases density and resistance of pervious concrete mix to abrasion parallelly reducing the porosity and water absorption. This signifies filler effect of GD on pervious concrete specimen.
3. Analysis of infiltration capacity reveals that increase in replacement reduces the infiltration capacity but not below the specified limits. This factor also signifies the micro filling ability of fine granite particles.
4. Micromechanical analysis using FTIR, XRD and SEM/EDAX are in line with inferences obtained from analysis of other mechanical properties. Though FTIR results show no characteristic variation owing to the lower replacement percentage, results of XRD and SEM/EDAX show that GD replacement aids in enhancement of strength owing to its micro filling ability.
5. Results of water purification analysis show that with increase in replacement percentage all the six parameters namely TSS, COD, BOD, TOC, TP, and TN with maximum removal obtained for phosphate and minimum removal in case of suspended solids. While minimum removal of TSS is owing to the higher pore size of specimen, higher reduction in other parameters is owing to the mechanical retention and microbial degradation.

Thus, from the study it is understood that replacement using GD tends to enhance the mechanical, durability and water purification ability pervious concrete samples. Mix with 1% replacement can be used in places like pavement shoulders that require a nominal compressive strength of 12 to 14 MPa whereas mix with 2% replacement serves as a better mix for utilisation in places that requires enhanced water quality. In future, study focusing on life cycle assessment of GD replaced pervious pavements and ability of the pavements to curtail CO_2 percentage in atmosphere can be performed.

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author contribution

The authors confirm contribution to the paper as follows: ***Experimental investigation, draft manuscript preparation:*** *Abhinaya M,* ***Interpretation of results, Validation:*** *Parthiban R,* ***Review and editing, Validation of manuscript:*** *Sivakumar N. All authors reviewed the results and approved the final version of the manuscript.*

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