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Influence of aggregate–binder and water–binder ratios on pervious concrete properties: An RSM approach

ABSTRACT

Traditional concrete pavements are impermeable in nature and it do not allow the water to enter in to the ground during rainy season.Pervious concrete is a special type of concrete being used in construction industry and offering a sustainable solution for storm water management and ground water recharge. This research focuses on Response Surface Methodology (RSM) with a Box-Behnken design to systematically evaluate different parameters such as aggregate size, quantities of ordinary Portland cement (OPC), Portland Pozzolana Cement (PPC) and coarse aggregate content for analysing the influence the mechanical performance of pervious concrete mixes. Through comprehensive testing and statistical analysis, the study uncovers complex interactions of the mix components, facilitating the identification of optimal formulations to achieve a balance between strength and sustainability for diverse applications. The main aim of this present study, is to study the properties of pervious concrete with varying Aggregate Binder (A/B) and Water Binder(W/B) ratio ranging from 3 - 2.9 and 0.3 - 0.35. All the mixes were tried with OPC and PPC binders using aggregate sizes viz. 6.3 mm, 9.4mm and 12.5 mm respectively. Test results proved that, mix containing more binder content with higher water cement ratio (M9) showcased higher mechanical strength properties than other mixes (M1-M8) due to enriched paste coating around the aggregate surface. Mix M1 has shown higher permeability and porosity due to lesser binder quantity and the adequate water-cement ratio results in slower rate of hydration process resulting in more void formation. Better strength properties are observed in smaller size aggregates which attributed to a dense microstructure. Increase in aggregate size results in decrease in strength whereas permeability and porosity increase.

Keywords: *Response Surface Methodology (RSM), Aggregate Binder (A/B) Ratio, Water Binder (W/B) Ratio, Pervious Concrete (PC), Aggregate Size (AS)*

1. INTRODUCTION

Global warming is the major concern that leads to abnormal rain and floods. Urban cities are being affected by natural calamities and in recent days, abundant quantity of rainfall in limited duration is a major concern which leads to storm water runoff. Pervious concrete, a revolutionary innovation in the field of construction technology represents a paradigm shift in approach towards traditional concrete applications. The impermeable nature of conventional concrete leads to increased stormwater runoff whereas pervious concrete is designed to allow water to pass through its porous structure.

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The uniqueness of it makes it a powerful tool in addressing environmental concerns related to urban development and stormwater management. Pervious concrete (PC) is distinguished by its interconnected void structure, that results in high porosity typically ranging from 15% to 35% [1].This design feature creates interconnected voids that enable water to infiltrate through the surface and into the underlying soil. A standout feature of pervious concrete is its ability to mitigate stormwater runoff. By facilitating water infiltration, it helps reduce the risk of flooding, erosion, and the transportation of pollutants into water bodies. Pervious concrete aligns with sustainable construction practices by promoting natural process. It acts as a filter, trapping pollutants and sediments from storm water and contributes to improved water quality. The success of pervious concrete lies in its meticulous mix design. A specific blend that incorporates a reduced amount of fines is crucial in creating the necessary voids for optimal water infiltration while maintaining adequate strength. Engineers and architects must carefully consider project requirements and site conditions to ensure the longevity and effectiveness of pervious concrete applications. Pervious concrete should be designed with appropriate permeability especially in road sub base that should range from 2 mm/sec to 6 mm/sec [2]. Notable strength increment was observed in the specimens made with small size aggregates. Moreover, an increased contact area between aggregates contributes to enhanced strength characteristics in the proposed pervious concrete. Variations in water – to binder ratio and aggregate size play a crucial role in influencing the relationship between the material's strength and durability [3].Aggregate grading and size have major influence in deciding permeability and porosity properties. The performance of pervious concrete pertaining to aggregate size can be determined by maintaining constant water binder ratio. The thickness of binder paste coating around the aggregates, width of contact between the aggregates and the point of contact play a major role in deciding permeability, porosity and strength properties of pervious concrete. The thickness of binder paste coating can be effectively calculated by determining specific surface area and fractional dimensional area of aggregates [4, 5].Mix containing larger size aggregates causes ravelling when it is subjected to undergo wheel abrasion. Moreover, the factors like binder quality, contact area and optimum cement paste content influence the compressive strength properties. Aggregate binder ratio ranging between 2.1 and 6.14 and water binder ratio ranging between 0.16 and 0.36 produce pervious concrete with remarkable properties. Furthermore, many studies were made with water binder ratio in the range of 0.3 [6].The permeability and the clogging study were conducted in the mix containing aggregate grading ranging from 2.36 mm to 4.75 mm and 4.75 mm to 6.3 mm. Specimens made with smaller size aggregate exhibit smaller pores that result in decrease in permeability properties [6].For every 10% increase in porosity, compressive strength reduces by approximately 50% [7]. The use of single sized aggregate results in greater permeability but with reduced strength properties. Maintaining same mix proportion with smaller aggregate size leads to reduction in workability and strength properties and it can be improved by using appropriate additives [8].Experimental date can be successfully analysed by using Analysis of Variance (ANOVA) and Multi Linear Regression Analysis (MLRA) [9]. Major studies have been carried out by performing linear regression analysis. When the experimental model contains various parameters, functional correlation model using Artificial Neural Networks (ANN) provides better outputs [9]. Evaluating problems with effective optimization can be performed through Response Surface Methodology (RSM) which is a statistical method with mathematical procedure [10] recommends to use single size aggregate or grading ranging from 19 mm to 9.5 mm. It is suggested to use pre-washed aggregates in the mix, so that aggregates remain free from impurities. Utilization of recycled aggregate in pervious concrete mix significantly reduces the workability property. Furthermore, 16.43% to 54.70% decrease in compressive strength was noticed for 15% increase in recycled concrete aggregate [11, 12]. ANN model shows better performance in predicting strength and permeability properties. Theoretical results arrived through ANN model has better correlation with experimental results. Inclusion of aggregate properties like coefficient of uniformity, gradation coefficient parameter in ANN model is highly recommended to achieve better outputs [13]. In the case of single size aggregate, 24% of decrease in compressive strength was noticed when porosity design changes from 15% to 25% and the same trend followed in flexural strength [14]. Mix made with 50% replacement of recycled concrete's w/c ratio of 0.25 possessed 28.9 MPa at 28 days. Fly ash addition exhibits a decline in mechanical property at early days with increased permeability. Nevertheless, permeability decreases with increased fly ash addition. The workability performance can be highly improved by using 0.2% water reducing agent of the cement mass. It also results in remarkable durability properties [15].The compressive strength and the internal hydration structure is directly related to binder content. The binder content is the critical element of consideration in determining the compressive strength and structure of pervious concrete. Too much binder fills the voids and decrease porosity, while too little binder fails to adequately coat the aggregate particles, thereby reducing the compressive strength of the mix [16]. Pervious concrete made with higher compaction energy level shows higher density property [17, 18].Authors observed that, PC mix with 10% Sugarcane Bagasse Ash (SBA) possessed better mechanical and durability properties due to denser C-A-S-H matrix. Incorporation of fine aggregate in PC mix significantly improves the filtration property [19].Higher strength was noticed in the samples having more thickness with enhanced compaction [20] while, higher density was also observed in those samples. Longitudinal cracks are observed in PC samples made with continuous gradation recycled coarse aggregates [21]. Better compressive strength was observed in PC samples made with A/B ratio 0.28 with decrease in permeability and increase in A/B ratio beyond 0.28 [22]. Addition of Supplementary Cementitious Materials (SCM's) in PC mixture also leads to significant decrease in infiltration property [23].

The impact of independent variables on experimental results can be analysed using the Design of Experiments (DOE) method. DOE allows for the optimization of test variables by establishing relationships between the empirical model and independent variables, ultimately providing the optimal response for experimental data. To efficiently determine the effect of independent variables with minimal experiments, statistical and mathematical techniques such as DOE, particularly Response Surface Methodology (RSM) can be employed [24]. Due to its high accuracy, RSM is widely utilized in concrete technology. In this study, Box-Behnken Design (BBD) within RSM was applied to optimize the composition of progression variables Aggregate Size, OPC, PPC and Coarse aggregate to evaluate their influence on compressive strength, split tensile strength and flexural strength. Convolutional Neural Network (CNN) using Root Mean Square Error (RMSE), Mean Absolute Percentage Error (MAPE) and Mean Absolute Error (MAE) exhibited lesser error metrics when compared to traditional approaches [25-27]. The authors studied the Unconfined Compressive Strength (UCS) of pervious concrete using RSM approach and also found that compaction timing ranging from 13 to 82 seconds significantly increased the UCS property.Limited research studies were performed using different aggregate sizes and water binder ratio and their effect on strength and permeability relationship. Hence, an attempt has been made to overcome the research gap using RSM approach with Box-Behnken design to optimize the mix parameters, mechanical and hydraulic properties of pervious concrete.

Significant contributions of the research include the investigating the strength and hydraulic properties of pervious concrete using mixes with different A/B and W/B ratios and optimization of the mixes using RSM.Furthermore, integration of IoT technologies in the pavement construction system improves the performance with respect to monitoring and maintenance.

2. RESPONSE SURFACE METHODOLOGY

Response Surface Methodology (RSM) is a statistical technique used to analyse and optimize all parameters where multiple input variables influence the output variables. It is preferred over other optimization techniques due to its efficiency in managing complex interactions between variables [24, 28-29]. RSM allows the development of empirical models to explore and optimize mix proportions thus making it invaluable in concrete research. Its systematic approach requires fewer experimental runs than full factorial designs thus saving time and costs while delivering accurate results [26-30]

In this study, Box Behnken design (BBD), a key tool in RSM was employed to analyse the effects of aggregate size, volume of OPC, volume of PPC and volume of coarse aggregate on the mechanical behaviour in concrete. The independent variables AS (X_1), OPC (X_2),PPC (X_3) and CA (X_4) were studied for their impact on mechanical performance of pervious concrete at 28 days. The predictive model developed through BBD accurately represents these relationships, enables optimization of mix proportions for enhanced strength and sustainability in pervious concrete and fosters eco-friendly concrete solutions. The reaction achieved is in (Eq.1)

$$Z = f(X_{1,}X_{2,}X_3, X_4) \quad (1)$$

A second-order model (Eq.2)was employed to represent the relationship between the response function and the input variables, providing a detailed explanation of the changes in concrete strength parameters.

$$Z = l_0 + \sum l_i x_i + \sum l_i x_i^2 + \sum\sum l_{ij} x_i x_j \quad (2)$$

Here, y represents the desired response variable, while l_0, i , lj, lij denotes the regression coefficients. The Design of Experiments (DOE) for the RSM must include the factors and variable levels corresponding to the four responses under investigation, as outlined in Table 1. To assess the effects of AS, OPC, PPC and CA concrete strength properties, the four-factor BBD method has been applied to 27 concrete mixes, as detailed in Table 4.

Table 1. Levels of variables

Variables	Minimum	Maximum
AS($\boldsymbol{X_1}$)	0	12.5
OPC($\boldsymbol{X_2}$)	0	491
PPC($\boldsymbol{X_3}$)	0	491
CA($\boldsymbol{X_4}$)	0	1425

3. MATERIALS AND METHODS

3.1. Materials

Ordinary Portland cement (OPC) of grade 53 (confirming to [33]) was used in this present study to make OPC binder. The specific gravity of OPC was 3.08. Initial and final setting time of OPC was found to be 85 minutes and 290 minutes respectively. Portland Pozzolana Cement (PPC) (confirming to [34]) was procured from local market. Specific gravity, initial and final setting of PPC was found to be 3.04, 50 minutes and 125 minutes respectively. The chemical composition of OPC and PPC were determined and showcased in Table 2. The test results are within acceptable limits as per codal provisions [31, 32]. Single sized coarse aggregate of size 6.3 mm, 10 mm and 12 mm was used and it was procured from crusher unit named APAT blue metals, Erode, Tamilnadu, India. Physical property tests of coarse aggregate were carried out [33] and the results are presented in Table 3.

Table 2. Chemical Composition of OPC and PPC

Constituents	CaO	SiO_2	Al_2O_3	Fe_2O_3	MgO	SO_3	Cl-	LOI
Composition (%) in OPC	60.52	18.72	4.25	3.08	3.51	2.85	0.07	3.65
Composition (%) in PPC	42.33	32.52	10.65	4.08	3.25	1.86	0.017	3.12

Table 3. Physical Properties of Coarse Aggregates

S.No.	Test details	Experimental results		
		6.3 mm	10 mm	12.5 mm
1.	Specific gravity	2.60	2.68	2.73
2.	Aggregate Impact value (%)	16.65	17.15	17.56
3.	Aggregate Crushing value (%)	18.38	19.25	21.25
4.	Loose Density (kg/m3)	1492	1460	1442
5.	Compacted Density (kg/m3)	1640	1592	1573
6.	Water absorption (%)	1.00	0.93	0.90

Table 4. Mix Proportion of OPC and PPC Binder Pervious Concrete

Mix ID	A/B ratio	W/B ratio	Aggregate Size (mm)	OPC (kg/m^3)	PPC (kg/m^3)	Coarse aggregate (kg/m^3)	Water (kg/m^3)
M1	3	0.3	6.3	475	475	1425	142.5
			8	454	454	1362	136.2
			12.5	412	412	1236	123.6
M2	3	0.325	6.3	475	475	1425	154.3
			8	454	454	1362	147.5
			12.5	412	412	1236	133.9
M3	3	0.35	6.3	475	475	1425	166.2
			8	454	454	1362	158.9
			12.5	412	412	1236	144.2
M4	2.95	0.3	6.3	483	483	1425	144.9
			8	461	461	1362	138.3
			12.5	418	418	1236	125.4
M5	2.95	0.325	6.3	483	483	1425	156.9
			8	461	461	1362	149.8
			12.5	418	418	1236	135.8
M6	2.95	0.35	6.3	483	483	1425	169.0
			8	461	461	1362	161.3
			12.5	418	418	1236	146.3
M7	2.9	0.3	6.3	491	491	1425	147.3
			8	469	469	1362	140.7
			12.5	426	426	1236	127.8
M8	2.9	0.325	6.3	491	491	1425	159.5
			8	469	469	1362	152.4
			12.5	426	426	1236	138.4
M9	2.9	0.35	6.3	491	491	1425	171.8
			8	469	469	1362	164.1
			12.5	426	426	1236	149.1

3.2. Mix design

Mix design of OPC and PPC binder pervious concrete was made as per recommendations mentioned in [11]. The aggregate size, water binder ratio and aggregate binder ratio were considered as predominant factor in mixture design. Nine mixes were performed by varying aggregate binder and water binder ratio. The mix proportions arrived is presented in Table 4. The aggregate of size 6.3 mm, 10 mm and 12.5 mm was used in this present study to predict the effect of aggregate binder ratio and water binder ratio on strength and permeability properties of pervious concrete. In present study, mix made with Ordinary Portland Cement binder and Portland Pozzolana Cement binder has been designated as OPC and PPC respectively. While the aggregate size is mentioned in suffix of every mix ID.

3.3 Experimental Programme

The present study predicts the strength of concrete and the permeability of pervious concrete using varying parameters such as aggregate size, aggregate binder ratio and water binder ratio. A total of 243 specimens were made to investigate the compressive strength [34], split tensile strength [35] and flexural strength [34] properties of pervious concrete at the age of 7 days and 28 days. Falling head permeability test was done [37] to predict the permeability properties of pervious concrete. A falling head permeability test setup was fabricated in laboratory and is shown in Figure 1.

Cylindrical specimen size of 150 mm diameter and 150 mm height was used to determine the coefficient of permeability at the age of 28 days using Darcy's law (Eq.3) [37].

$$\text{Coefficient of permeability, } k = (A_1 l/A_2 t)\log(h_2/h_1) \quad (3)$$

Where, the cross-sectional area of specimen and drain pipe are denoted as A_1 and A_2, t denotes the time taken from initial head to final head for the flow of water (h_1 to h_2), and l is the length of the specimen. The porosity percentage and the dry density of pervious concrete were determined from specimen of size 70.6 mm x 70.6 mm x 70.6 mm at the age of 28 days. The percentage of pores in the concrete mix was determined with (Eq.4) [36, 37].

$$\text{Porosity (\%)} = (V_T - V_C) / V_T \quad (4)$$

Where, V_T is the total volume of the specimen in mm^3 and V_T-V_C is the void space volume in mm^3.

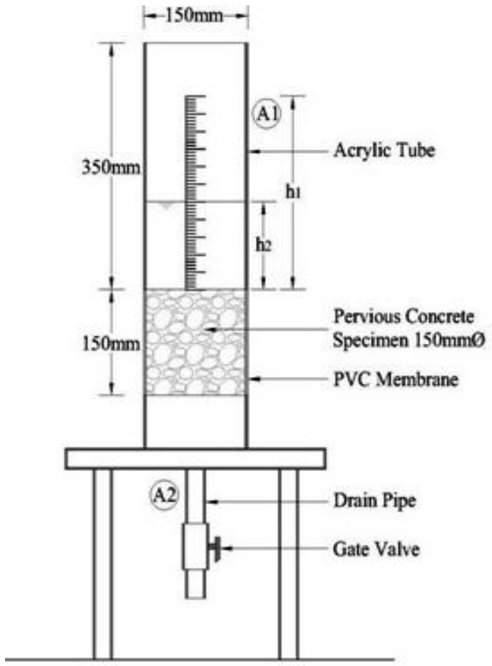


Figure 1. Falling Head Permeability Setup

4. RESULTS AND DISCUSSION

The strength properties of hardened pervious concrete specimens are investigated through the tests such as compressive strength, split tensile strength and flexural strength. Table 5 show case strength properties observed at the age of 28 days for different aggregate binder and water binder ratio. The physical properties of pervious concrete were measured by falling head permeability test, porosity test and dry density test at the age of 28 days.

Table 5. Mechanical Properties of OPC and PPC Binder Pervious Concrete

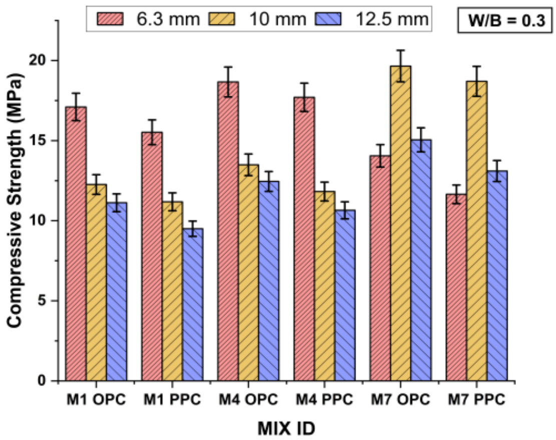
Mix ID	A/B ratio	W/B ratio	Aggregate size (mm)	Compressive Strength (MPa)		Split Tensile Strength (MPa)		Flexural Strength (MPa)	
				OPC	PPC	OPC	PPC	OPC	PPC
M1	3	0.3	6.3	17.10	15.52	1.88	1.71	2.89	2.76
			10	12.26	11.18	1.35	1.23	2.45	2.34
			12.5	11.12	9.50	1.22	1.05	2.33	2.16
M2	3	0.325	6.3	19.27	18.28	2.12	2.01	3.07	2.99
			10	13.86	12.18	1.52	1.34	2.61	2.44
			12.5	11.3	10.37	1.24	1.14	2.35	2.25
M3	3	0.35	6.3	20.20	19.25	2.22	2.12	3.15	3.07
			10	16.38	14.39	1.80	1.58	2.83	2.66
			12.5	12.50	11.25	1.38	1.24	2.47	2.35
M4	2.95	0.3	6.3	18.66	17.7	2.05	1.95	3.02	2.94
			10	13.49	11.82	1.48	1.30	2.57	2.41

			12.5	12.45	10.65	1.37	1.17	2.47	2.28
M5	2.95	0.325	6.3	20.29	19.24	2.23	2.12	3.15	3.07
			10	14.59	12.82	1.60	1.41	2.67	2.51
			12.5	12.89	10.95	1.42	1.20	2.51	2.32
M6	2.95	0.35	6.3	22.05	20.91	2.43	2.30	3.29	3.20
			10	17.24	15.15	1.90	1.67	2.91	2.72
			12.5	14.05	11.65	1.55	1.28	2.62	2.39
M7	2.9	0.3	6.3	19.65	18.7	2.16	2.06	3.10	3.03
			10	15.05	13.1	1.66	1.44	2.72	2.53
			12.5	13.5	11.1	1.49	1.22	2.57	2.33
M8	2.9	0.325	6.3	22.31	21.16	2.45	2.33	3.31	3.22
			10	16.05	14.11	1.77	1.55	2.80	2.63
			12.5	14.1	12.25	1.55	1.35	2.63	2.45
M9	2.9	0.35	6.3	23.1	21.52	2.54	2.37	3.36	3.25
			10	18.96	16.67	2.09	1.83	3.05	2.86
			12.5	15.51	12.65	1.71	1.39	2.76	2.49

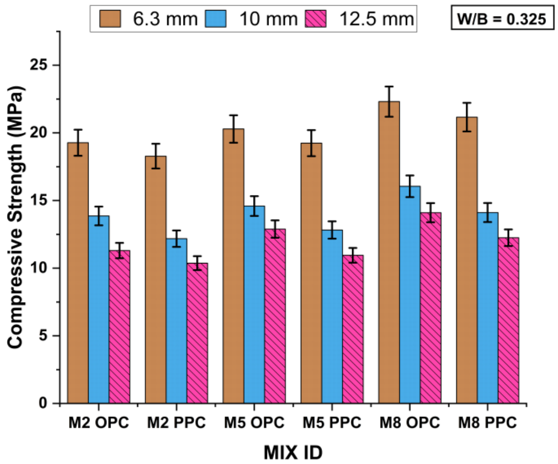
4.1. Mechanical properties

4.1.1. Compressive Strength

Nine combination mixes (M1-M9) were performed for determining optimum aggregate binder and water binder ratio such as 3, 2.95, 2.9 and 0.3, 0.325 and 0.35 respectively. Amongst nine mixes, mix made with A/B ratio 2.9 and W/B 0.35 (M9) showed better strength properties rather than other mixes (M1-M8). This stands in line with the fact that excess binder content observed in the mix results in better hydration process in both OPC and PPC binder and it results in strength gain at earlier ages. At the age of 28 days, M9 mix made with $PPC_{6.3}$ exhibits 6.8% lesser compressive strength than $OPC_{6.3}$. Similarly, 12.1% and 18.4% declined compressive strength was noticed in mix PPC_{10} and $PPC_{12.5}$ when compared with OPC_{10} and $OPC_{12.5}$. This is due to slower hydration process observed in PPC blend with respect to OPC blend. The results are also graphically represented in Figure 2 (a-c).



(a)



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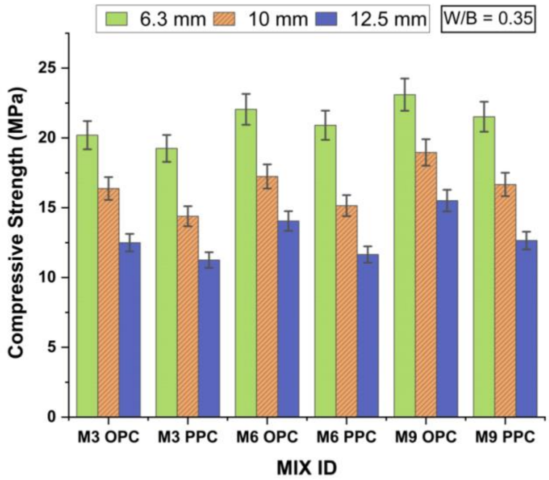
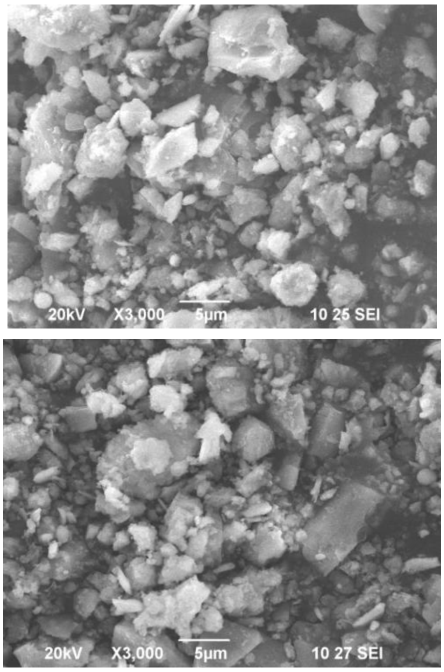


(c)

Figure 2. (a-c) Compressive Strength of OPC and PPC Binder Pervious Concrete

In order to investigate the hydration behaviour of OPC and PPC binder, Scanning Electron Microscope (SEM) study was carried out at Karunya University, Coimbatore, Tamilnadu, India. SEM image of OPC blend (Figure.3a) confirms the formation of Calcium – Silicate – Hydrate (C-S-H) gel in the form of fibrous shape, Calcium hydroxide $Ca(OH)_2$ in the form of plate shape, and ettringite in the form of needle shape. This can be attributed to the fact that the aforesaid compound highly enhances the hydration behaviour of OPC blend. Figure3 (b) represents the SEM image of PPC blend. Through the image, Calcium – Silicate – Hydrate (C-S-H) gel and Calcium hydroxide $Ca(OH)_2$ formation were identified in the form of fibrous and plate shape which leads to improvement of micro structure behaviour of PPC blend. Furthermore, limited unhydrated fly ash particles were observed in the form of spherical particles that slow down the hydration process and results in lesser strength at earlier ages.



(a)
(b)

Figure 3. (a) SEM Image of OPCBlendFigure.3 (b) SEM Image of PPC Blend

Aggregate size is a crucial element to be taken into account in deciding strength properties of pervious concrete. Smaller size aggregate mix showcased higher strength properties than larger size aggregates. This implies that; smaller size aggregate mix has dense packing effect that results in higher compressive strength.

4.1.2. Split Tensile Strength

Figure 4 (a-c) depicts the split tensile strength of OPC and PPC binder pervious concrete at the age of 28 days. Test results proved that, Mix M9 showcased higher split tensile strength properties rather than other mixes (M1-M8). At 28thday, M9 mix made of PPC binder with 6.3 mm aggregate possessed 6.7% lesser split tensile strength than $OPC_{6.3}$. Similarly, 12.4% and 18.7% lesser split tensile strength was observed in PPC_{10} and $PPC_{12.5}$when compared with OPC_{10} and $OPC_{12.5}$ respectively. The decrease of split tensile strength in PPC binder mix was noticed due to inadequate production of hydration products that makes weak ITZ (Interfacial Transition Zone) in the concrete microstructure. Regardless of aggregate size, smaller size aggregate mix showed higher split tensile strength properties than mix made with larger size aggregates. This can be attributed to that fact that; larger size aggregate mix has more pore structure and so it results in weaker bonding in aggregate interfacial transition zone.

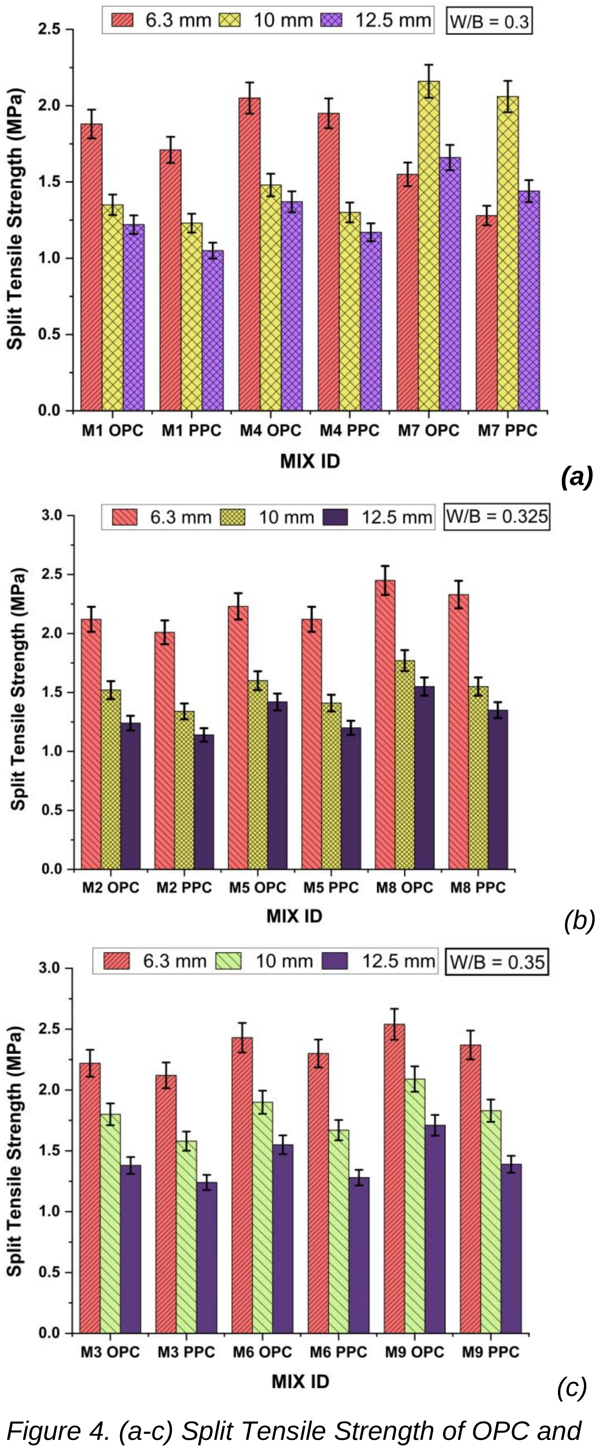
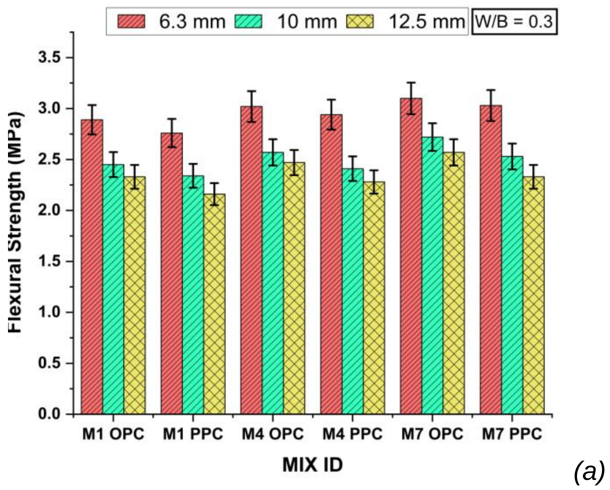
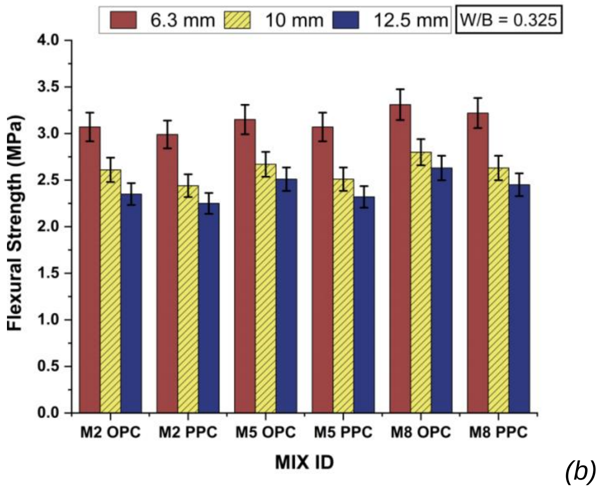


Figure 4. (a-c) Split Tensile Strength of OPC and PPC Binder Pervious Concrete

4.1.3. Flexural Strength

Flexural strength of OPC and PPC binder pervious concrete at the age of 28 days was observed and is graphically represented in Figure 5 (a-c). M9 mix demonstrated higher flexural strength properties when compared with other mixes (M1-M8). At the age of 28 days, M9 mix made of PPC binder with 6.3 mm aggregate possessed 3.3% lesser flexural strength than $OPC_{6.3}$. Similarly, 6.2% and 9.8% lesser flexural strength was seen in PPC_{10} and $PPC_{12.5}$when compared with OPC_{10} and $OPC_{12.5}$ respectively. Slower rate of hydration observed in PPC mix reduces strength at earlier ages. With respect to aggregate size, the similar trend is observed in compressive strength and split tensile strength. Mix made with smaller size aggregate showed dense microstructure that significantly increases the flexural strength property of concrete.





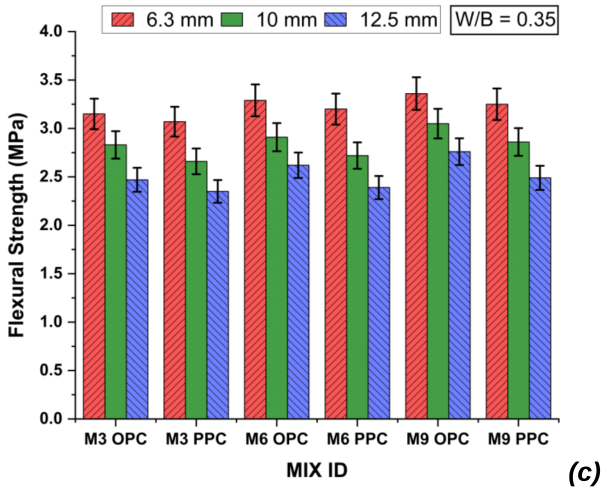


Figure 5. (a-c) Flexural Strength of OPC and PPC Binder Pervious Concrete

4.2. Physical properties

Table 6 presents the physical properties of pervious concrete at the age of 28 days and the results are discussed elaborately.

Table.6. Physical Properties of OPC and PPC Binder Pervious Concrete

Mix ID	A/B ratio	W/B ratio	Aggregate size, (mm)	Permeability (cm/sec)		Porosity (%)		Density, (kg/m^3)	
				OPC	PPC	OPC	PPC	OPC	PPC
M1	3	0.3	6.3	1.20	1.35	18.19	19.66	1897	1806
			10	1.90	2.14	21.85	23.61	1795	1690
			12.5	2.39	3.06	23.92	25.77	1706	1668
M2	3	0.325	6.3	1.11	1.25	16.84	18.20	2062	1963
			10	1.76	1.98	20.23	21.86	1951	1837
			12.5	2.21	2.84	22.15	23.86	1854	1813
M3	3	0.35	6.3	1.03	1.16	15.59	16.85	2360	2246
			10	1.63	1.84	18.73	20.24	2233	2102
			12.5	2.05	2.63	20.51	22.09	2121	2074
M4	2.95	0.3	6.3	1.14	1.28	17.32	18.72	1997	1901
			10	1.81	2.04	20.81	22.49	1890	1779
			12.5	2.27	2.92	22.78	24.54	1796	1755
M5	2.95	0.325	6.3	1.06	1.19	16.04	17.33	2171	2066
			10	1.67	1.89	19.27	20.82	2054	1934
			12.5	2.11	2.70	21.09	22.72	1952	1908

M6	2.95	0.35	6.3	0.98	1.10	14.85	16.05	2484	2364
			10	1.55	1.75	17.84	19.28	2350	2213
			12.5	1.95	2.50	19.53	21.04	2233	2183
M7	2.9	0.3	6.3	1.09	1.22	16.45	17.78	2197	2091
			10	1.72	1.94	19.77	21.36	2079	1957
			12.5	2.16	2.77	21.64	23.31	1975	1931
M8	2.9	0.325	6.3	1.01	1.13	15.24	16.47	2388	2273
			10	1.59	1.80	18.30	19.78	2259	2031
			12.5	2.00	2.57	20.04	21.59	2147	2003
M9	2.9	0.35	6.3	0.93	1.05	14.11	15.25	2608	2482
			10	1.47	1.66	16.95	18.32	2468	2324
			12.5	1.85	2.38	18.55	19.99	2345	2292

Test results proved that, mix made with A/B ratio 2.95 and W/B ratio 0.3 (M1) showed higher permeability and porosity properties. With respect to type of binder, PPC blend has higher permeability than OPC blend. $PPC_{6.3}$ shows 12.5% high coefficient of permeability than $OPC_{6.3}$. 12.6% and 28% higher coefficient of permeability was noted in PPC_{10} and $PPC_{12.5}$ mix than OPC_{10} and $OPC_{12.5}$ mix. While comparing with all mixes, M1 has lesser A/B ratio and W/B ratio which results in slower hydration process in both OPC and PPC binder and it results in high pores in the concrete. The aforesaid mechanism increases the permeability property whereas strength properties are vice versa. Regardless of aggregate size, larger aggregate showcased higher permeability properties due to higher void formation observed in the mix.

Amongst all mixes, M1 mix has higher porosity than other mixes (M2-M9). In M1 mix, $PPC_{6.3}$mix has 8.1% higher porosity than $OPC_{6.3}$ mix. Moreover, 8.1% and 7.7% increased porosity was highlighted in PPC_{10} and $PPC_{12.5}$ mix when compared with OPC_{10} and $OPC_{12.5}$ mix. This property has significant influence in increasing permeability property in mix M1. However, mix containing more pores exhibits lesser density property. Test results proved that, mix M9 shows higher density property than other mixes (M1-M8). $PPC_{6.3}$mix shows 4.8% lesser density than $OPC_{6.3}$. 5.8% and 2.3% lesser density were observed in PPC_{10} and $PPC_{12.5}$ mix when compared with OPC_{10} and $OPC_{12.5}$ mix respectively. It was also noticed that, mix with higher density showed better strength properties due to dense micro structure property. The compressive strength results are in conformity with the same property. With respect to aggregate size, smaller size aggregate possessed higher density property than larger size aggregate mix. This result tends to a discussion that, smaller size aggregate results in dense packing effect that significantly decreases the pores inside the concrete structure and thus it results in higher density property.

5. RSM MODELLING – OBSERVATIONS AND DISCUSSIONS

The regression equation derived from the RSM model is crucial in estimating and optimizing the Compressive Strength (CS), Splitting Tensile Strength (STS) and Flexural Strength (FS). To analyze the impact of progression variables such as AS, OPC, PPC and CA on the Compressive Strength (CS) SPLIT Tensile Strength (STS) and Flexural Strength (FS) properties of concrete, BBD was employed in this study. The main aim of choosing BBD technique is it requires limited experimental values than other techniques. A total of 27 experimental results, as shown in Table 4 were evaluated for each response, with the findings represented in (Eqs.5-10)

$$fcs_{opc} = -13.33 - 1.3X_1 + 0.65X_2 + 0.75X_3 - 0.280X_4 * X_2 + 0.062X_1^2 + 0.00047X_2^2 - 0.00025X_3^2 + 0.000172X_4^2 - 0.0084X_1 * X_2 + 0.0189X_1 * X_3 - 0.00318X_1 * X_4 - 0.00139X_2 * X_3 - 0.000250X_2 * X_4 - 0.000042X_3 * X_4 \quad (5)$$

$$fcs_{ppc} = -2.4X_1 + 0.28X_2 + 0.63X_3 - 0.316X_4 * X_2 + 0.080X_1^2 + 0.00086X_2^2 - 0.00003X_3^2 + 0.000194X_4^2 - 0.0068X_1 * X_2 + 0.0191X_1 * X_3 - 0.00329X_1 * X_4 - 0.00141X_2 * X_3 - 0.000239X_2 * X_4 - 0.000096X_3 * X_4 \quad (6)$$

$$fSTS_{opc} = -14.9 - 0.15X_1 + 0.072X_2 + 0.083X_3 * X_2 - 0.0307X_4 + 0.0069X_1^2 + 0.000050X_2^2 - 0.000092X_3^2 + 0.000194X_4^2 - 0.00092X_1 * X_2 + 0.00206X_1 * X_3 - 0.00350X_1 * X_4 - 0.000152X_2 * X_3 - -0.000027X_2 * X_4 - 0.000004X_3 * X_4 \quad (7)$$

$$fSTS_{ppc} = 0.9 - 0.26X_1 + 0.029X_2 + 0.069X_3 * X_2 - 0.0353X_4 + 0.0089X_1^2 + 0.000097X_2^2 -- 0.000002X_3^2 + 0.000022X_4^2 - 0.00076X_1 * X_2 + 0.00210X_1 * X_3 - 0.000367X_1 * X_4 - 0.000155X_2 * X_3 - -0.000026X_2 * X_4 - 0.0000011X_3 * X_4 \quad (8)$$

$ffs_{opc} = -13.1 - 0.07X_1 + 0.066X_2 + 0.068X_3 - 0.0243X_4 + 0.0056{X_1}^2 + 0.000037{X_2}^2 - 0.000024{X_3}^2 + 0.00015{X_4}^2 - 0.00080X_1{*}X_2 + 0.00155X_1{*}X_3 - 0.000265X_1{*}X_4 - 0.000125X_2{*}X_3 - -0.000024X_2 * X_4 - 0.000002X_3{*}X_4$ (9)

$ffs_{ppc} = -0.5 - 0.018X_1 + 0.036X_2 + 0.057X_3 - 0.0294X_4 + 0.0075{X_1}^2 + 0.000073{X_2}^2 - -0.000004{X_3}^2 + 0.00018{X_4}^2 - 0.00065X_1{*}X_2 + 0.00163X_1{*}X_3 - 0.000282X_1{*}X_4 - 0.000130X_2{*}X_3 - -0.000025X_2 * X_4 - 0.000006X_3{*}X_4$ (10)

Table 7. Analysis of Variance

	(fcs_{opc})			fcs_{ppc}			$(fSTS_{opc})$		
Source	DF	F-Value	P-Value	DF	F-Value	P-Value	DF	F-Value	P-Value
Model	14	0.63	0.794	14	0.66	0.774	14	0.62	0.801
Linear	4	1.09	0.403	4	1.21	0.356	4	1.08	0.409
X_1	1	0.69	0.421	1	0.50	0.494	1	0.68	0.424
X_2	1	1.67	0.221	1	2.02	0.181	1	1.65	0.223
X_3	1	0.56	0.470	1	0.54	0.478	1	0.55	0.473
X_4	1	1.46	0.251	1	1.80	0.205	1	1.43	0.254
Square	4	0.30	0.870	4	0.35	0.841	4	0.30	0.874
${X_1}^2$	1	0.12	0.732	1	0.18	0.676	1	0.12	0.732
${X_2}^2$	1	0.18	0.676	1	0.56	0.469	1	0.17	0.689
${X_3}^2$	1	0.05	0.826	1	0.00	0.982	1	0.06	0.816
${X_4}^2$	1	0.80	0.388	1	0.93	0.354	1	0.77	0.396
2-Way Interaction	6	0.55	0.763	6	0.50	0.798	6	0.54	0.770
$X_1{*}X_2$	1	0.27	0.611	1	0.16	0.696	1	0.27	0.615
$X_1{*}X_3$	1	1.37	0.265	1	1.27	0.282	1	1.34	0.269
$X_1{*}X_4$	1	0.22	0.646	1	0.22	0.650	1	0.22	0.647
$X_2{*}X_3$	1	1.20	0.295	1	1.13	0.309	1	1.19	0.298
$X_2 * X_4$-	1	0.22	0.646	1	0.19	0.674	1	0.21	0.655
$X_3{*}X_4$	1	0.01	0.938	1	0.03	0.866	1	0.00	0.946

Table 7. Analysis of Variance

	$(fSTS_{ppc})$			ffs_{opc}			ffs_{ppc}		
Source	DF	F-Value	P-Value	DF	F-Value	P-Value	DF	F-Value	P-Value
Model	14	0.66	0.774	14	0.63	0.794	14	0.66	0.773
Linear	4	1.20	0.360	4	1.06	0.416	4	1.21	0.356
X_1	1	0.49	0.497	1	0.69	0.423	1	0.52	0.485
X_2	1	1.98	0.184	1	1.59	0.231	1	1.90	0.193
X_3	1	0.54	0.478	1	0.49	0.496	1	0.51	0.490
X_4	1	1.79	0.205	1	1.48	0.246	1	1.92	0.191
Square	4	0.35	0.837	4	0.31	0.863	4	0.35	0.837
${X_1}^2$	1	0.19	0.672	1	0.13	0.722	1	0.20	0.663
${X_2}^2$	1	0.58	0.461	1	0.15	0.704	1	0.49	0.496
${X_3}^2$	1	0.00	0.988	1	0.06	0.804	1	0.00	0.968
${X_4}^2$	1	0.94	0.351	1	0.82	0.383	1	0.98	0.342
2-Way Interaction	6	0.50	0.797	6	0.56	0.754	6	0.50	0.800
$X_1{*}X_2$	1	0.16	0.693	1	0.33	0.578	1	0.18	0.675
$X_1{*}X_3$	1	1.27	0.282	1	1.24	0.287	1	1.15	0.304
$X_1{*}X_4$	1	0.22	0.646	1	0.21	0.658	1	0.20	0.666
$X_2{*}X_3$	1	1.13	0.309	1	1.31	0.275	1	1.18	0.298
$X_2 * X_4$-	1	0.18	0.677	1	0.28	0.607	1	0.25	0.629
$X_3{*}X_4$	1	0.03	0.864	1	0.00	0.966	1	0.01	0.906

From Analysis of variance (ANNOVA) as shown in Table7, the linear terms, particularly OPC and CA exhibit relatively higher F-values (up to 2.02), suggesting that these factors may have a more noticeable effect on the strength characteristics. While not statistically significant at the 95% confidence level, their influence indicates promising areas for further investigation, potentially with a larger dataset or refined modelling approaches. The results show a consistent pattern across different strength parameters cs ,$fSTS$,ffs for both OPC and PPC. This suggests that the tested variables, including aggregate size (AS), cement type (OPC/PPC), and coarse aggregate (CA) are influencing the response variables in a stable manner, which is essential for maintaining predictable performance in practical applications. The interaction term $X_1 * X_3$ shows an F-value of 1.37, indicating a potential positive effect of AS and PPC in combination. Similarly, $X_2 * X_3$ *and* $X_2 * X_4$ have F-values in the range of 1.13 to 1.31, suggesting that certain material combinations may enhance strength properties when optimized further. These interactions though not highly significant at the 95% confidence level highlight promising trends for material synergy and may be more pronounced with refined experimental conditions. The square terms, while exhibiting low F-values demonstrate model stability and confirm that no extreme nonlinear variations occur within the tested range of input factors. This ensures that the response surface does not exhibit unexpected fluctuations, making the results more reliable for practical use.

5.1. Lack of fit (p value) and Pareto analysis

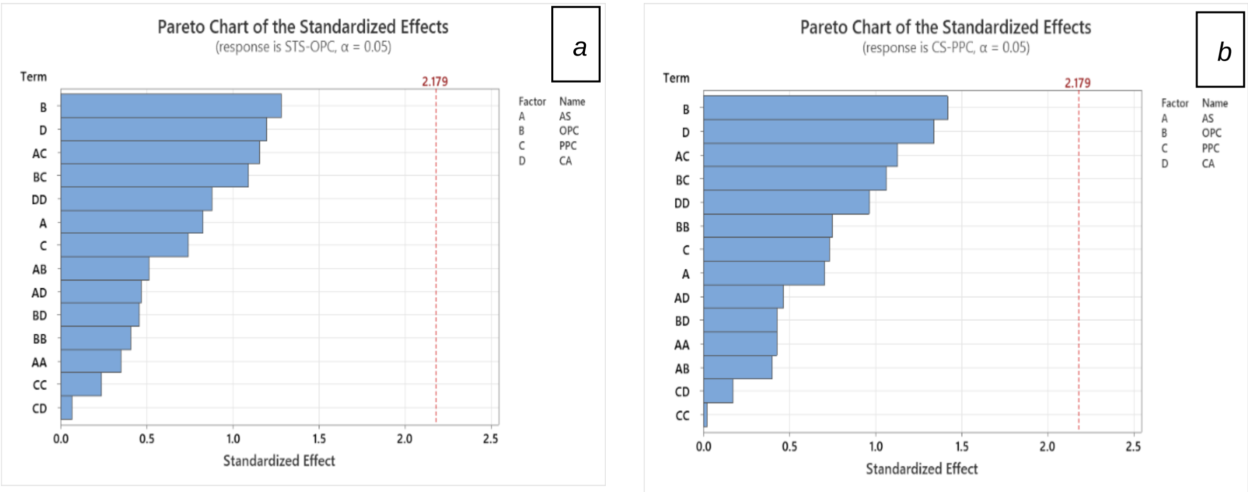


Figure 6. Pareto chart of the standardized effects for a)$\boldsymbol{fcs_{opc}}$ *b)* $\boldsymbol{fcs_{ppc}}$

The Pareto chart shown in Figure.6 illustrates the standardized effects of various factors on the compressive strength of OPC and PPC concrete fcs_{opc} and fcs_{ppc}at a significance level of α = 0.05. The red dashed line (threshold at 2.179) represents the minimum statistically significant effect. Any factor exceeding this line is considered significant in influencing compressive strength.

B (OPC content) has the highest standardized effect, indicating that it is the most influential factor in determining compressive strength. D (Coarse Aggregate - CA) follows as the second most significant factor. These two factors suggest that the cement composition and aggregate proportions are the primary determinants of concrete strength.AC (AS × PPC) and BC (OPC × PPC) exhibit moderate influence, suggesting that the combined effects of AS (Alkaline Solution) with PPC and OPC with PPC impact compressive strength.DD (CA × CA) and BB (OPC × OPC) also play a role, indicating non-linear effects where increasing these variables further might lead to diminishing or increasing returns.

From Figure.7, B (OPC content) has the highest standardized effect, confirming that Ordinary Portland Cement (OPC) plays the most critical role in split tensile strength. D (Coarse Aggregate - CA) follows closely, indicating that the properties of coarse aggregates significantly influence tensile strength.AC (AS × PPC) and BC (OPC × PPC) show notable effects, suggesting that the interaction between the alkaline solution (AS) and PPC, as well as OPC and PPC affects split tensile strength.DD (CA × CA) also exhibits an impact, implying that the variation in coarse aggregate content affects STS.

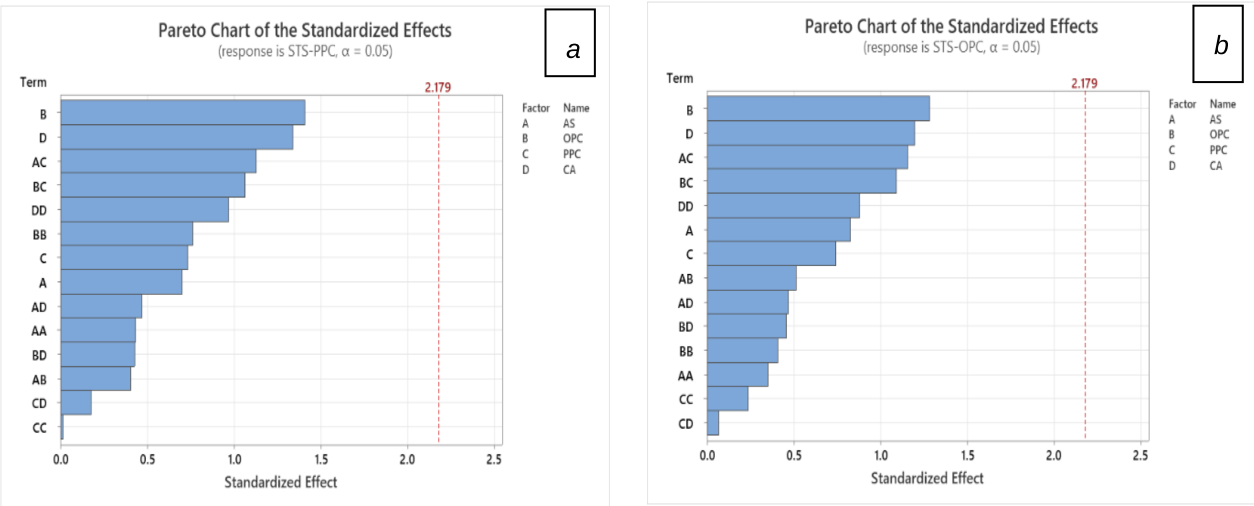


Figure 7. Pareto chart of the standardized effects for a)$fSTS_{opc}$ b) $fSTS_{ppc}$

B (OPC content) has the highest standardized effect, confirming that Ordinary Portland Cement (OPC) plays the dominant role in split tensile strength. D (Coarse Aggregate - CA) follows as the second most influential factor, suggesting that the aggregate properties strongly affect STS.AC (AS × PPC) and BC (OPC × PPC) show moderate effects, implying that the interaction between alkaline solution (AS) and PPC, as well as OPC and PPC, influences tensile strength.DD (CA × CA) also exhibits a notable effect, indicating that variations in coarse aggregate proportion have a nonlinear impact.

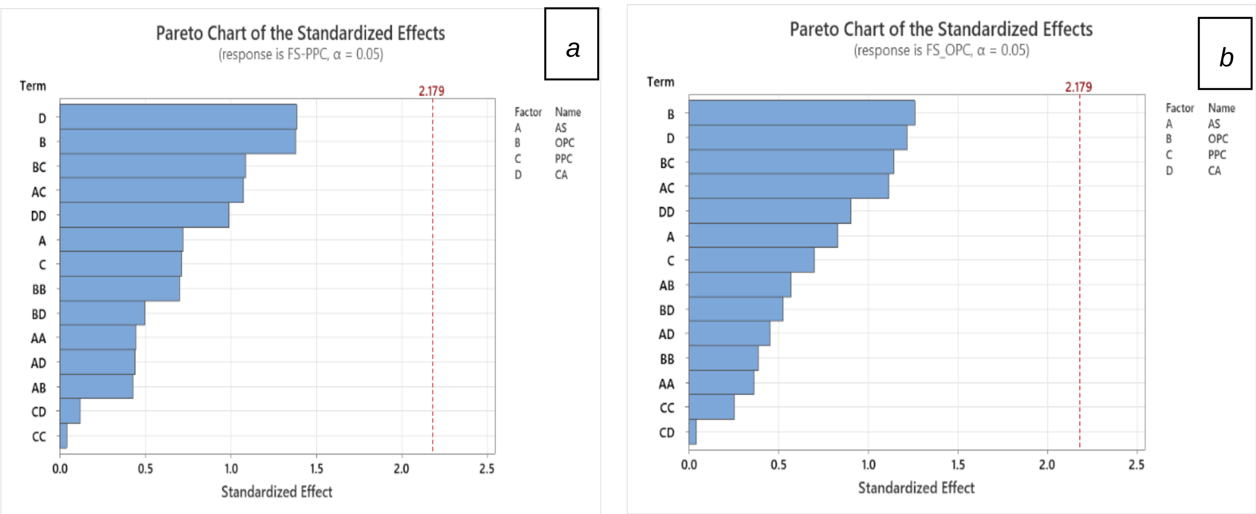


Figure 8. Pareto chart of the standardized effects for a)ffs_{opc} b) ffs_{ppc}

From Figure.8, B (OPC Content) is the most dominant factor to mean that the proportion of Ordinary Portland Cement (OPC) has the highest influence on flexural strength. D (Coarse Aggregate - CA) is the second most influential factor, highlighting the importance of coarse aggregate properties in flexural strength. BC (OPC × PPC) and AC (AS × PPC) interactions contribute significantly, indicating that the combination of OPC with PPC, as well as the effect of the alkaline solution (AS) with PPC affects flexural strength.DD (CA × CA) suggests that variations in coarse aggregate characteristics also play a role in determining flexural strength.

D (Coarse Aggregate - CA) is the most significant factor, suggesting that the properties and gradation of coarse aggregate have the highest impact on the flexural strength of PPC concrete. B (OPC Content) is the second most influential factor, indicating that the proportion of Ordinary Portland Cement (OPC) plays a crucial role in flexural strength, even in PPC-based mixtures. BC (OPC × PPC) and AC (AS × PPC) interactions are notable, meaning that the combination of OPC with PPC and the influence of the alkaline solution (AS) with PPC affects flexural strength.

5.2. Surface Plot Analysis and Optimization of Progression Variables

Figure 9-11 represent three-dimensional (3D) surface plots and it demonstrates the influence of progression variables on the responses.

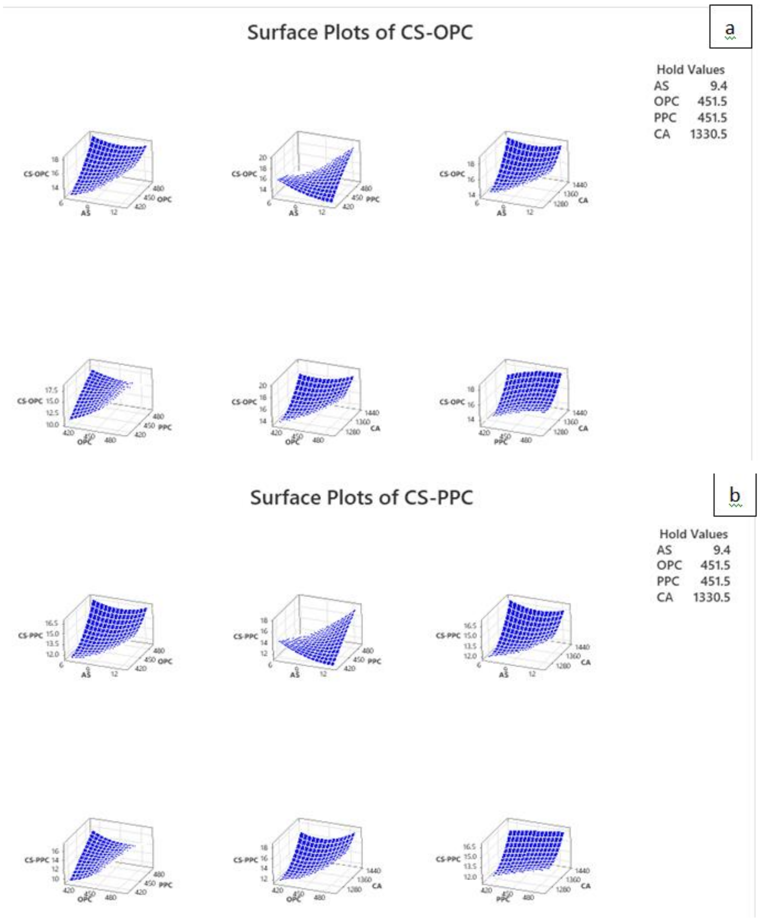


Figure 9. Surface plot for a) $\boldsymbol{fcs_{OPC}}$ *b)* $\boldsymbol{fcs_{ppc}}$

The surface plots provided in the document offer a comprehensive visualization of the interaction effects between different factors on the mechanical properties of the material, including compressive strength (CS), split tensile strength (STS), and flexural strength (FS) for both Ordinary Portland Cement (OPC) and Portland Pozzolana Cement (PPC). These plots help in identifying the nonlinear relationships among the variables, showcasing how material composition and processing parameters influence structural performance. The surface topography characterized by peaks and valleys, indicates that certain factor combinations lead to optimal strength properties, whereas others may cause significant reductions.

In Figure.9, for compressive strength (CS-OPC and CS-PPC), the surface plots reveal that the strength characteristics are highly dependent on material composition and interaction effects. The curvature of the plots suggests that OPC and PPC respond differently to variations in factors such as aggregate proportion, curing conditions, and cementitious composition. Higher compressive strength regions appear in specific zones, confirming that the optimized mixture design significantly influences structural load-bearing capacity. The response trends suggest that PPC exhibits a broader range of acceptable compositions compared to OPC, possibly due to its pozzolanic reaction contributing to long-term strength gains.

In Figure.10, the surface plots for split tensile strength (STS-OPC and STS-PPC) highlight the critical role of material composition and curing conditions in determining tensile performance. The observed variations indicate that tensile strength is highly sensitive to the fine aggregate ratio and binder content. The plots exhibit moderate curvature, implying a strong interaction effect, which means that optimizing tensile strength requires careful selection of factors rather than increasing individual parameters. Additionally, PPC mixtures tend to show delayed strength gains, reflecting the gradual pozzolanic reaction enhancing the tensile properties over time.

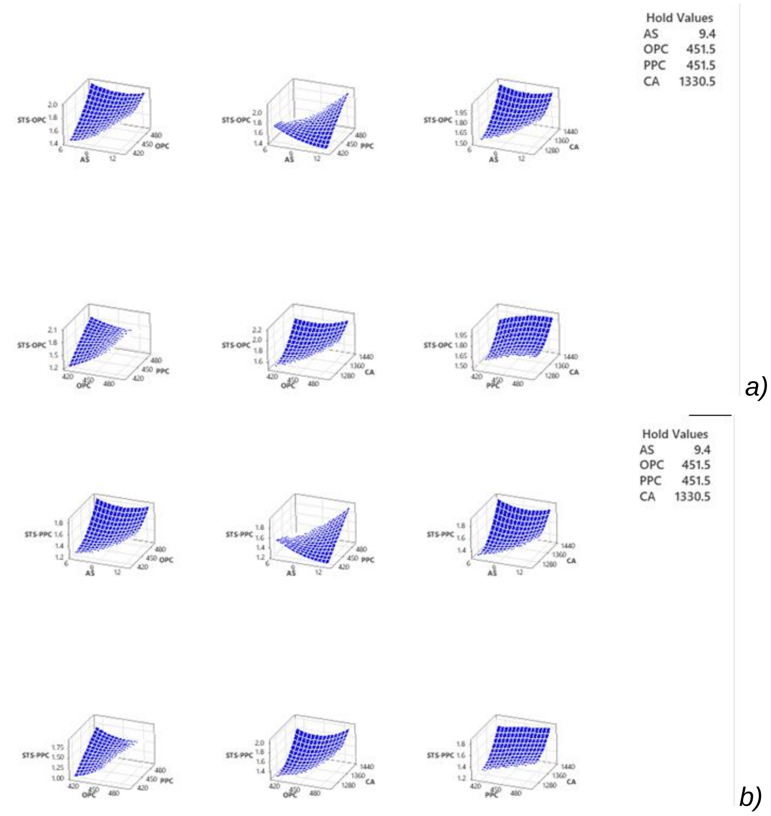


Figure 10. Surface plot for a) $fSTS_{OPC}$b)STS_{ppc}

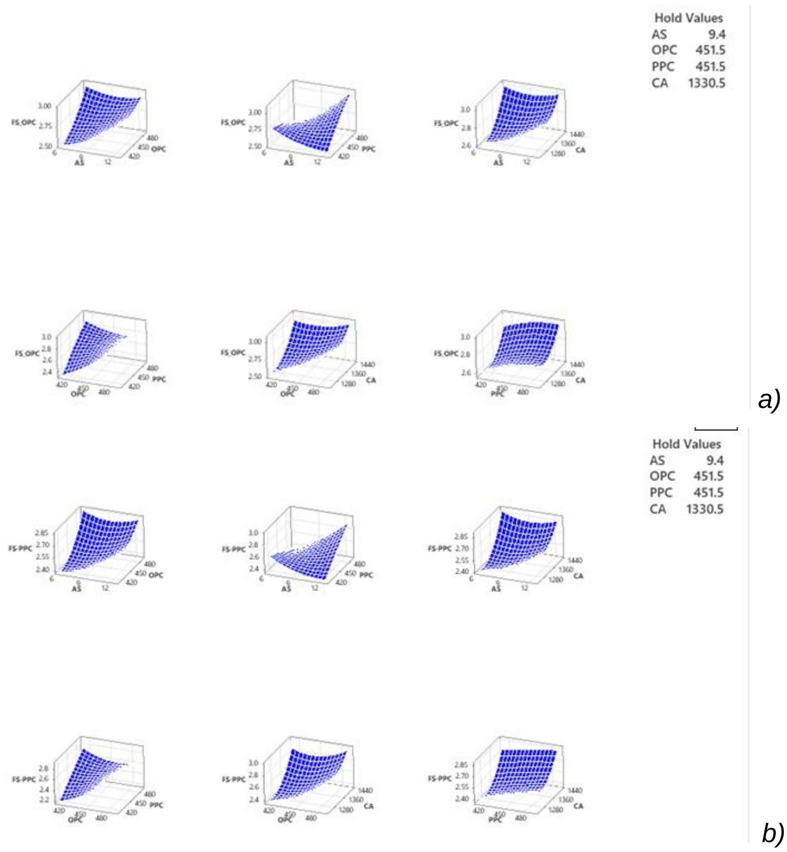


Figure 11. Surface plot for a) ffs_{OPC}b)ffs_{ppc}

In the case of flexural strength (FS-OPC and FS-PPC), the response surface plots as shown in Figure 11 indicate that bending resistance is significantly affected by the aggregate binder ratio and the water binder ratio. The interaction effects reveal that higher flexural strength is achieved under specific combinations of these parameters, emphasizing the importance of balance in the mix design. The surface curvature suggests that exceeding a certain threshold of binder content may lead to reduced flexural strength, likely due to excessive paste formation that weakens the bond between aggregates. PPC mixes exhibit more gradual variations, reinforcing their sustained strength development. The contour and gradient patterns of the surface plots suggest that there is an optimal region where multiple properties namely compressive, tensile, and flexural strength can be simultaneously optimized. The response plots indicate that excessive alterations in individual factors can lead to undesirable mechanical properties, emphasizing the importance of balanced mix proportions. The nonlinear interactions observed in the surface plots validate the complexity of the material behaviour, necessitating a multi-objective optimization approach to achieve the best performance.This present study focusses on investigation of strength and hydraulic properties of pervious concrete using single sized coarse aggregates such as 6.3 mm, 9.4 mm and 12.5 mm respectively. The present study will be enhanced by proposing the study based on broader aggregate gradations and durability aspects.

6. CONCLUSION

The effect of aggregate binder ratio (A/B) and water binder ratio (W/B) on mechanical and physical properties of pervious concrete using different aggregate sizes was determined. In addition, anRSM Based Prediction in A/B and W/B of Pervious Concrete has been analysed and the following conclusions are drawn.

- It is observed that mix M9 showcased higher strength properties rather than other mixes (M1-M8). Higher water binder ratio (W/B: 0.35) along with higher aggregate binder ratio (A/B: 2.95) produces the mix with higher paste consistency that results in denser microstructure which significantly increases strength properties. However, Mix M1-M8 achieved the adequate strength properties as laid down by pervious concrete codal specifications.
- From all mixes (M1-M9), PPC binder pervious concrete showed lesser strength properties than OPC binder pervious concrete. This is primarily due to the fact that slower rate of hydration observed in PPC mix reduces the strength at earlier ages. However, strength gain can be achieved in later ages due to continuous hydration effect.
- With respect to aggregate size of all the mixes (M1-M9), smaller size aggregate (6.3 mm) showed higher strength properties than larger size aggregate 10 mm followed by 12.5 mm. Smaller size aggregate mix showcased dense packing effect and made concrete microstructure dense to result in higher strength properties.Existing studies proved that, incorporation of SCMs, fibersenhance the performance of pervious concrete
- Mix M1 has higher percentage of porosity than other mixes (M2 to M9). Lesser A/B ratio (A/B: 3) and W/B (W/B: 0.3) ratio in the mix results in slower hydration process in both OPC and PPC binder that lead to formation of pores in the concrete structure. The aforesaid mechanism increases the permeability property whereas strength properties are vice versa.
- This study shows that mix (M1 – M9) showed adequate mechanical and physical properties as laid down by codal provisions for pervious concrete. With respect to strength requirement, M9 mix can be preferred and for permeability required applications M1 mix can be preferred.
- Based on RSM approach, OPC (B) and CA (D) dominate compressive strength development in PPC concrete, which aligns with expectations since cement hydration and aggregate quality significantly impact strength.
- It has been noticed that, coarse aggregate (D) plays a crucial role, suggesting that well-graded aggregates contribute to better load distribution and crack resistance in flexural behavior. Further, coarse aggregate (D) is the most critical factor in flexural strength, emphasizing that properly graded and strong aggregates contribute significantly to the load-carrying capacity and crack resistance of PPC-based concrete.

Disclosure statement

The authors declare that they have no conflict of interest.

7. REFERENCES

[1] S. Park, S. Ju, H.K. Kim, Y.S. Seo, S. Pyo (2022) Effect of the rheological properties of fresh binder on the compressive strength of pervious concrete, J. Mater. Res. Technol., 17, 636–648. https://doi.org/10.1016/j.jmrt.2022.01.045

[2] J. Sun, J. Zhang, Y. Gu, Y. Huang, Y. Sun, G. Ma (2019) Prediction of permeability and unconfined compressive strength of pervious concrete using evolved support vector regression, Constr. Build. Mater., 207, 440–449. https://doi.org/10.1016/j.conbuildmat.2019.02.117

[3] Y. Shin, H.M. Park, J. Park, H. Cho, S.E. Oh, S.Y. Chung, B. Yang (2022) Effect of polymer binder on the mechanical and microstructural properties of pervious pavement materials, Constr. Build. Mater., 325, 126209. https://doi.org/10.1016/j.conbuildmat.2021.126209

[4] S. Bright Singh, M. Murugan (2022) Effect of aggregate size on properties of polypropylene and glass fibre-reinforced pervious concrete, Int. J. Pavement Eng., 23(6), 2034–2048. https://doi.org/10.1080/10298436.2020.1836562

[5] P. Zhao, X. Liu, J. Zuo, H. Huangfu, R. Liu, X. Xie, X. Wang, T. Li, D. Liu, S.P. Shah (2024) Research on the strength prediction for pervious concrete based on design porosity and water-to-cement ratio, Rev. Adv. Mater. Sci., 63(1). https://doi.org/10.1515/rams-2022-0335

[6] A. Mulu, P. Jacob, G.S. Dwarakish (2022) Hydraulic performance of pervious concrete based on small size aggregates, Adv. Mater. Sci. Eng., 2022, 2973255.https://doi.org/10.1155/2022/2973255

[7] O. Deo, N. Neithalath (2010) Compressive behavior of pervious concretes and a quantification of the influence of random pore structure features, Mater. Sci. Eng. A, 528(1), 402–412. https://doi.org/10.1016/j.msea.2010.09.024

[8] K.S. Elango, V. Revathi (2017) Fal-G binder pervious concrete, Constr. Build.Mater., 140, 91–99. https://doi.org/10.1016/j.conbuildmat.2017.02.086

[9] R.A. Armstrong, S.V. Slade, F. Eperjesi (2000) Statistical review: An introduction to analysis of variance (ANOVA) with special reference to data from clinical experiments in optometry, Ophthalmic Physiol. Opt. www.elsevier.com/locate/ophopt

[10] J. Sridhar, D. Jegatheeswaran, R. Gobinath (2022) A DOE (response surface methodology) approach to predict the strength properties of concrete incorporated with jute and bamboo fibres and silica fumes, Adv. Civ. Eng., 2022, 1150837. https://doi.org/10.1155/2022/1150837

[11] ACI 522 R-10 (Reapproved 2011) Report on pervious concrete, American Concrete Institute, Farmington Hills, MI, USA.

[12] M.M. Muda, A.M. Legese, G. Urgessa, T. Boja (2023) Strength, porosity and permeability properties of porous concrete made from recycled concrete aggregates, Constr. Mater., 3(1), 81–92. https://doi.org/10.3390/constrmater3010006

[13] H.H. Almasaeid, D.G. Salman (2022) Application of artificial neural network to predict the properties of permeable concrete, Civ. Eng. Archit., 10(6), 2290–2305. https://doi.org/10.13189/cea.2022.100605

[14] H. Liu, G. Luo, H. Wei, H. Yu (2018) Strength, permeability, and freeze-thaw durability of pervious concrete with different aggregate sizes, porosities, and water-binder ratios, Appl. Sci., 8(8), 1217. https://doi.org/10.3390/app8081217

[15] R. Wu, S. Shi, Y. Shen, C. Hu, M. Luo, Z. Gan, B. Xiao, Z. Wang (2022) Effects of different factors on the performance of recycled aggregate permeable pavement concrete, Mater., 15(13), 4566. https://doi.org/10.3390/ma15134566

[16] V. Banevičienė, J. Malaiškienė, R. Boris, J. Zach (2022) The effect of active additives and coarse aggregate granulometric composition on the properties and durability of pervious concrete, Mater., 15(3), 1035. https://doi.org/10.3390/ma15031035

[17] K. Ferić, V. Sathish Kumar, A. Romić, H. Gotovac (2023) Effect of aggregate size and compaction on the strength and hydraulic properties of pervious concrete, Sustainability, 15(2), 1146. https://doi.org/10.3390/su15021146

[18] S. Marathe, M. Nieświec, B. Gronostajska (2024) Alkali-activated permeable concretes with agro-industrial wastes for a sustainable built environment, Mater., 18(1), 87. https://doi.org/10.3390/ma18010087

[19] M. Ziccarelli (2025) Mix design of pervious concrete in geotechnical engineering applications, Mater., 18(9), 1909. https://doi.org/10.3390/ma18091909

[20] A. Akkaya, İ.H. Çağatay (2024) Investigation of the effect of compression force on the tensile strength and infiltration rate of pervious concrete blocks, Buildings, 14(11), 3689. https://doi.org/10.3390/buildings14113689

[21] H. Lv, Z. Xiong, H. Li, J. Liu, G. Xu, H. Chen (2025) Investigating the mechanical properties and water permeability of recycled pervious concrete using three typical gradation schemes, Buildings, 15(3), 358. https://doi.org/10.3390/buildings15030358

[22] H. Bilal, X. Gao, L. Cavaleri, A. Khan, M. Ren (2024) Mechanical, durability, and microstructure characterization of pervious concrete incorporating polypropylene fibers and fly ash/silica fume, J. Compos. Sci., 8(11), 456. https://doi.org/10.3390/jcs8110456

[23] X. Bai, H. Zhou, X. Bian, X. Chen, C. Ren (2024) Compressive strength, permeability, and abrasion resistance of pervious concrete incorporating recycled aggregate, Sustainability, 16(10), 4063. https://doi.org/10.3390/su16104063

[24] Y. Moodi, S.R. Mousavi, A. Ghavidel, M.R. Sohrabi, M. Rashki (2018) Using response surface methodology and providing a modified model using whale algorithm for estimating the compressive strength of columns confined with FRP sheets, Constr. Build. Mater., 183, 163–170. https://doi.org/10.1016/j.conbuildmat.2018.06.081

[25] G. Yu, S. Zhu, Z. Xiang (2024) The prediction of pervious concrete compressive strength based on a convolutional neural network, Buildings, 14(4), 907. https://doi.org/10.3390/buildings14040907

[26] A. Hammoudi, K. Moussaceb, C. Belebchouche, F. Dahmoune (2019) Comparison of artificial neural network (ANN) and response surface methodology (RSM) prediction in compressive strength of recycled concrete aggregates, Constr. Build. Mater., 209, 425–436. https://doi.org/10.1016/j.conbuildmat.2019.03.119

[27] M. Adresi, A. Yamani, M.K. Tabarestani, G.H. Nalon (2024) A prediction model for the unconfined compressive strength of pervious concrete based on mix design and compaction energy variables using the response surface methodology, Buildings, 14(9), 2834. https://doi.org/10.3390/buildings14092834

[28] M. Aziminezhad, M. Mahdikhani, M.M. Memarpour (2018) RSM-based modeling and optimization of self-consolidating mortar to predict acceptable

ranges of rheological properties, Constr. Build. Mater., 189, 1200–1213. https://doi.org/10.1016/j.conbuildmat.2018.09.019

[29] S.J.S. Chelladurai, R. Arthanari, A.N. Thangaraj, H. Sekar (2017) Dry sliding wear characterization of squeeze cast LM13/FeCu composite using response surface methodology, China Foundry, 14(6), 525–533. https://doi.org/10.1007/s41230-017-7101-3

[30] S.J.S. Chelladurai, R. Arthanari, R. Selvarajan, R. Kanagaraj, P. Angappan (2018) Investigation on microstructure and tensile behaviour of stir cast LM13 aluminium alloy reinforced with copper coated short steel fibers using response surface methodology, Trans. Indian Inst. Met., 71(9), 2221–2230. https://doi.org/10.1007/s12666-018-1353-5

[31] IS 12269-2013 Specification for grade 53 ordinary portland cement, Bureau of Indian Standards, New Delhi, India.

[32] IS 1489 Part 1-1991 (Reaffirmed 2014) Specification for portlandpozzolana cement, Bureau of Indian Standards, New Delhi, India.

[33] IS 2386 Part 1-1963 (Reaffirmed 2011) Methods of test for aggregates for concrete – particle size and shape, Bureau of Indian Standards, New Delhi, India.

[34] IS 516-1959 (Reaffirmed 2013) Methods for test for strength of concrete, Bureau of Indian Standards, New Delhi, India.

[35] IS 5816-1999 (Reaffirmed 2013) Splitting tensile strength of concrete method of test, Bureau of Indian Standards, New Delhi, India.

[36] ASTM Standard Test Method for density, absorption, and voids in hardened concrete, ASTM International, West Conshohocken, PA, USA.

[37] K.S. Elango, V. Revathi (2019) Infiltration and clogging characteristics of pervious concrete, Asian J. Civ. Eng., 20(8), 1119–1127. https://doi.org/10.1007/s42107-019-00170-w

IZVOD

UTICAJ ODNOSA AGREGAT-VEZIVO I VODA-VEZIVO NA SVOJSTVA PROPUSNOG BETONA: RSM PRISTUP

Tradicionalni betonski kolovozi su nepropusni po prirodi i ne dozvoljavaju vodi da prodre u zemlju tokom kišne sezone. Propusni beton je posebna vrsta betona koja se koristi u građevinskoj industriji i nudi održivo rešenje za upravljanje obornskim vodama i obnavljanje podzemnih voda. Ovo istraživanje se fokusira na metodologiju površine odziva (RSM) sa Box-Behnken dizajnom kako bi se sistematski procenili različiti parametri kao što su veličina agregata, količine običnog portland cementa (OPC), portland pocolana cementa (PPC) i sadržaj krupnog agregata za analizu uticaja na mehaničke performanse propusnih betonskih mešavina. Kroz sveobuhvatno testiranje i statističku analizu, studija otkriva složene interakcije komponenti mešavine, olakšavajući identifikaciju optimalnih formulacija za postizanje ravnoteže između čvrstoće i održivosti za različite primene. Glavni cilj ove studije jeste proučavanje svojstava propusnog betona sa različitim odnosom agregata i veziva (A/B) i vode i veziva (W/B) u rasponu od 3 - 2,9 i 0,3 - 0,35. Sve mešavine su isprobane sa OPC i PPC vezivima koristeći veličine agregata, naime 6,3 mm, 9,4 mm i 12,5 mm, respektivno. Rezultati ispitivanja su pokazali da mešavina koja sadrži veći sadržaj veziva sa višim odnosom vode i cementa (M9) pokazuje veća mehanička svojstva čvrstoće od drugih mešavina (M1-M8) zbog obogaćenog premaza paste oko površine agregata. Mešavina M1 je pokazala veću propustljivost i poroznost zbog manje količine veziva, a adekvatan odnos vode i cementa rezultira sporijom brzinom procesa hidratacije, što rezultira većim formiranjem šupljina. Bolja svojstva čvrstoće primećena su kod agregata manje veličine, što se pripisuje gustoj mikrostrukturi. Povećanje veličine agregata dovodi do smanjenja čvrstoće, dok se propustljivost i poroznost povećavaju.

Ključne reči*: Metodologija površine odziva (RSM), Odnos veziva i agregata (A/B), Odnos veziva i vode (W/B), Propusni beton (PC), Veličina agregata (AS)*

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