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Studies on Characterization of Pervious Concrete for Pavement Applications

M.Uma Maguesvari[a,c*] and V.L. Narasimha[b]

[a] *Research Scholar, Dept. of Civil Engg, Pondicherry Engineering College, Puducherry*
[b]*Professor , Dept. of Civil Engg, Pondicherry Engineering College, Puducherry*
[c]*Asst Professor , Dept. of Civil Engg, Rajalakshmi Engineering College,Chennai*

Abstract

This study presents the influence of fine aggregate and coarse aggregate quantities on the properties of pervious concrete. Materials used are OPC Type I, fine aggregate corresponding to grading II and four sizes of coarse aggregate namely, 4.75mm to 9mm, 9mm to 12.5mm, 12.5mm to 16mm, 16mm to 19.5mm. Mixes were prepared with the water cement ratio of 0.34, cement content of 400kg/m^3 and maintaining the aggregate cement ratio as 4.75:1. Fine aggregate was replaced with coarse aggregate in the range of 50 - 100 % by weight. Various mechanical properties of the mixes were evaluated. Coefficient of permeability was determined by using falling head permeability method. The relationship between the strength, abrasion resistance, permeability and total void present in aggregate based on angularity number has been developed. Suitability of pervious concrete as a pavement material is discussed.

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Key words: Pervious concrete; Permeability; Angularity number; Total void; Fatigue.

1. Introduction

Due to rapid urbanization most of the places are covered with impermeable surfaces like cement concrete. This has a major impact on the ground water table. Pervious Concrete pavement is an effective ways to minimize this issue. Pervious concrete is an open graded structure with interconnected voids through which rain and storm water is permitted to percolate into the aquifer. It consists of cement, coarse aggregate, some percentage of fine aggregate and water. Pervious concrete is an environmental friendly building material and EPA (Environmental Protection agency) has identified it as a Best Management Practice (BMP) for storm water Management.

* Corresponding author. Tel.: +91944344595.
E-mail address: umamaguesvari@gmail.com

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It can be used for lower traffic roads, shoulders, sidewalks and parking lots. This will add points to a project with a sustainable material managing storm water, reducing ground water pollution.

Cement paste in permeable concrete is very thin layer which binds coarse aggregate. Porous concrete tends to fail at the binder interface between the aggregate and its results in the low compressive strength (Yang and Jiang, 2003). Normally, the water cement ratio is one of the important factors for the compressive strength of cement concrete. However, in case of pervious concrete the above concept may have little significance. Because, water is essential to produce the fresh cement paste with a good workability but not clog up all the pores. Optimum range of water cement ratio for both strength and permeability point of view ranges from 0.30 to 0.38(Y. Zhuge and C.Lian, 2009). Porosity of the porous concrete varies from 15% to 30%, by volume, and it depends on the type of compaction and the type of the aggregates (Neithalath.N and Bentz D.P, 2010). High range Water reducer and thickening agent are introduced in the concrete to improve its strength and workability (Aamer Raffique et al, 2012). Addition of styrene butadiene latex is found to improve the compressive strength but reduce permeability (An cheng et al, 2011). Latex polymer, Styrene Butadiene rubber and sand up to 7% are introduced in concrete to improve its strength. It reduces permeability which shows the void content is less still within an acceptable range greater than 15%. Compressive strength varies from 7 to 15 MPa (Baoshan Haowu et al, 2010). Efforts are being made to increase the strength characteristics by replacing the up to 40% sand with coarse aggregate and OPC was replaced with fly ash and the compressive strength was attained in the range of 65 MPa to 117 Mpa (Chetan Hazaree2006). Attempts have also been made to improve the fatigue strength of Porous concrete (Yu Chen et al, 2013).

Whereas the important parameter that affects the voids in aggregate is its angularity, which is characterized by its sharp edges. If the aggregate is angular, voids in the aggregate will increase. This surface property is very significant in the assessment of the volume of voids in the aggregate. However, no systematic study on the effect of angularity of aggregate on the voids content of concrete is reported. This paper presents a systematic work to address the same.

2. Experimental Program

2.1. Materials and properties

Constituent used were cement, crushed gravel as coarse aggregate, fine aggregate and water. Type I Portland cement conforming to ASTM C 150 was used in all mixes, Crushed gravel was used as coarse aggregate. Four single sized coarse aggregate namely, 4.75mm to 9mm, 9mm to 12.5mm, 12.5mm to 16mm, 16mm to 19.5mm which covers the full range of 522 R-10 Pervious Concrete was used in the present study. Fine aggregate used in the work conform to Zone II of IS: 383- 1978. Table 1 presents the physical properties of materials.

Table 1. Physical properties of materials

Properties	Value
Specific gravity (SSD)of Coarse aggregate	2.71
Specific gravity (OD)of Coarse aggregate	2.70
Specific gravity of fine aggregate	2.62
Specific gravity of cement	3.15

2.2. Mix proportion

Experimental work was chosen with cement content 400kg/m^3, water cement ratio of 0.34 based on an earlier study (C. Lian & Y. Zhuge, 2010). Four Control mixes corresponding to four aggregate sizes are proportioned as per IS: 10262-2001 by absolute volume method. Control mixes are designed as M1FC, M2FC, M3FC and M4FC. The fine aggregate content in the above mixes was selected as one of the study parameter. An attempt was made to quantify the effect of the fine aggregate on the voids content in the aggregate matrix. Accordingly, the fine aggregate was varied between 0% and 50%. The reference mixes were re-proportioned for a constant volume. A total of 24 mixes studied. Details of these mixes are presented in Tables 2 and 3.

Table2. Designation of the mixes

Percentage of fine aggregate	16.0 to19.5mm	12.5 to 16.0mm	9.0 to 12.5mm	4.75 to 9.0mm
(Control mix)	M1FC	M2FC	M3FC	M4FC
50	M1F50	M2F50	M3F50	M4F50
40	M1F40	M2F40	M3F40	M4F40
30	M1F30	M2F30	M3F30	M4F30
20	M1F20	M2F20	M3F20	M4F20
10	M1F10	M2F10	M3F10	M4F10
0	M1F0	M2F0	M3F0	M4F0

Table 3. Mix proportions of pervious concrete

Name of the Mix	Mix Ratio	Material quantity(Kg/m^3)	
		Fine aggregate	Coarse aggregate
M1F0, M2F0, M3F0, M4F0	1:0:4.75	0	1916
M1F10, M2F10, M3F10, M4F10	1:0.1875:4.56	75	1841
M1F20, M2F20, M3F20, M4F20	1:0.375:4.575	150	1766
M1F30, M2F30, M3F30, M4F30	1:0.56:4.19	224	1692
M1F40, M2F40, M3F40, M4F40	1:0.75:4	299	1617
M1F50, M2F50, M3F50, M4F50	1:0.935:3.855	374	1542
M1FC, M2FC, M3FC, M4FC	1:1.87:2.92	748	1168

2.3. Preparation and Testing of Specimen

2.3.1 Total void in aggregates

Total void content of aggregate was determined by angularity number method as per IS: 2386-part -1.

Note: Designation M- Mix, digit 1- 4 indicate aggregate size, F- Fine aggregate, next two digits indicate % of fine aggregate, C- indicates control

2.3.2. Compressive strength

Compressive strength test were conducted in accordance with ASTM C 39. Cubes of specimen of size 100 mm x 100 mm x 100 mm were prepared for each mix. After 24 hours the specimens were de molded and cured in water for 24ºC until testing. The strength value was reported as the average of three samples.

2.3.3. Flexural Strength

Flexural strength was obtained from three point method according to ASTM C 78 the test were carried out after 28 days of curing on the beam sample of size 100 mm x 100 mm x 500mm.

2.3.4. Split Tensile Strength

Split Tensile strength was obtained in accordance with ASTM C 496. Cylindrical specimens of 100 mm x 200 mm were cast and tested after 28 days curing.

2.3.5. Abrasion Resistance

Abrasion resistance of pervious concrete was determined by casting the specimens of size 60 mm x 60 mm x 25mm and tested after 28 days of curing as per IS:2386 part - 4.

2.3.6. Permeability

Permeability of pervious mixes was determined by using falling head permeability method based on earlier study (Narayanan Neithalath , Jason Weiss & Jan Olek, 2006).Specimen of size 80 mm diameter and 150 mm length were casted and tested after 28 days of curing .

3. Results and discussion

3.1. Total Void in aggregate based on Angularity number

Table 4 presents the angularity number for four sizes of aggregate. When the angularity number increases, the percentage of voids present in the aggregate also increases. From Table 4 showed that there is a decrease in angularity number from Mix M1F0 to M4F0. It was also observed that the size of aggregate has pronounced effect on the voids (Table 5). Based on the concepts of angularity number the total void present in the aggregate are determined for all the mixes along with fine aggregate. Evidently with the increase of fine aggregate decreases the total void.

Table 4. Angularity number for various sizes of aggregate

Mix Details	Angularity Number
M1F0	8
M2F0	7
M3F0	6
M4F0	4

Table 5. Total Voids Present in Aggregates

	M1	M2	M3	M4
F0	40.91	39.51	39.34	37.42
F10	39.54	37.55	37.45	35.81
F20	37.04	35.67	35.63	33.93
F30	33.46	33.08	32.70	31.84
F40	31.19	30.63	30.67	30.01
F50	28.88	28.30	28.19	28.13

3.2 . Strength Characteristics

Fig 1, Table 6 and 7 shows the compressive strength, flexural strength and split tensile strength with various curing periods. The specimens with all the four selected size of aggregate followed the same trend. Fine aggregate increases in mix resulted in increase of compressive strength. It is observed, that as the size of coarse aggregate decreases, compressive strength is increased. This is due to the increase in contact area, which increased, as the aggregate size is reduced. More importantly, the cohesive agent, namely sand, and the cement hydration products co-mingle and create two interpenetrating matrices which work together, resulting in improved strength (Baoshan Huang, Hao Wu, Xiang Shu & Edwin G. Burdette, 2010).The average increase in compressive strength from 7 to 28 days were 27%. Similarly there is an increase in 24% of compressive strength from 28 to 56 days. From Table 7 and Fig.1 it is seen that by decrease in angularity number gradually from M1F0 to M3F0 induce a constant increment of compressive strength of about 0.5 N/mm^2. Similar trend was observed for the flexural strength and split tensile strength as shown in Fig 2 and 3.

Table 6. Strength of control Mix

Mix Details	Compressive Strength (N/mm^2)			Flexural Strength (N/mm^2)	Split Tensile Strength (N/mm^2)
	7 days	28 days	56 days	28 days	28 days
M1FC	24.9	34.4	42.73	3.8	3.75
M2FC	25.2	34.6	43.17	4.0	3.82
M3FC	25.5	36.63	44.70	4.4	3.94
M4FC	27.63	41.9	48.40	5.2	4.21

Table 7. Compressive strength of pervious concrete at various ages

Mix Details	Compressive Strength (N/mm^2)		
	7 days	28 days	56 days
M1F0	5	9.6	11.53
M1F10	7.17	10.3	14.80
M1F20	9.3	11.13	19.33
M1F30	11.6	16.5	23.57
M1F40	11.9	21.56	28.07
M1F50	14.43	23.6	31.77
M2F0	6.2	10.03	12.17
M2F10	7.21	11	16.97
M2F20	10.4	13	20.83
M2F30	12.2	18.8	23.37
M2F40	14.4	23	28.10
M2F50	15.2	24.26	34.40

Mix Details	Compressive Strength (N/mm^2)		
	7 days	28 days	56 days
M3F0	6.53	10.3	12.07
M3F10	7.36	11.23	15.30
M3F20	10.9	15.2	20.27
M3F30	13.2	22	25.70
M3F40	15.3	23.7	29.07
M3F50	16.23	24.8	34.33
M4F0	6.6	11	12.70
M4F10	8.1	12	15.90
M4F20	11.3	16	20.67
M4F30	13.4	23.12	28.13
M4F40	15.6	24.32	29.57
M4F50	18.1	26.2	35.47

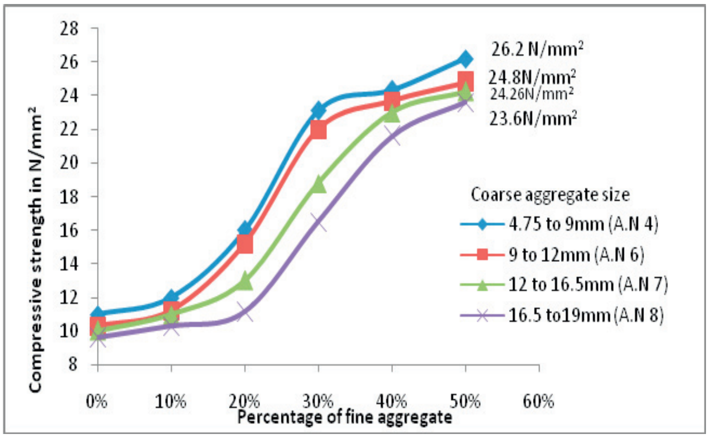

Fig.1. Variation of compressive Strength (28 days) on fine aggregate content

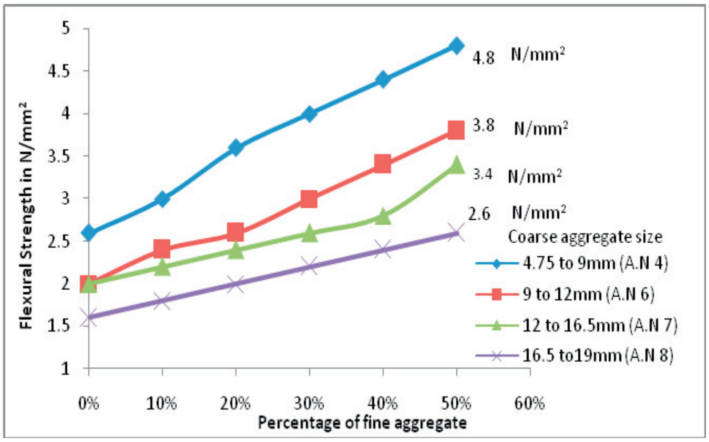

Fig.2. Variation of flexural strength (28 days) on fine aggregate content

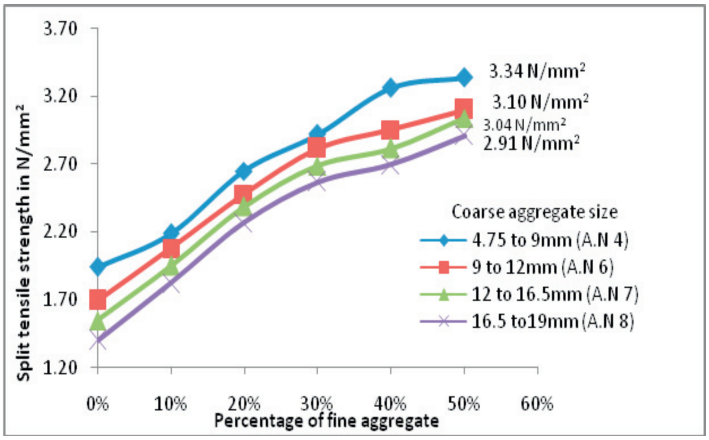

Fig.3. Variation of split tensile strength (28 days) on fine aggregate content

Note: Designation A.N – Angularity Number

The flexural strength and split tensile strength increased with increase in percentage of fine aggregate. Table 5 denotes that there is a reduction of angularity number with the influence of fine aggregate in the mixes. Void, which is an indicative parameter of the angularity number, influences the strength in the mixes which is shown in the Fig 1, 2 and 3. Whereas for those mixes without fine aggregate there is a raise in compressive by about 2.6 % for M2 and M3 mixes and for M3 and M4 mixes it is about 6.4%. The reduction in angularity number in above mixes yield increase in compressive strength. With the addition of fine aggregate in the mixes M1 and M2 increase in compressive strength by 7.7%, for M2 and M3 it increase by 7.1% ,similarly M3 and M4 it increases by 13.5%. This shows that there is a definite correlation between angularity number, Value of voids present in aggregate and its corresponding strength.

3.3. Permeability

Results of permeability of the pervious concrete mixtures are shown in Table 8. Pervious concrete mix with small size aggregates produce less permeability, when compared with the mix with large size aggregate. Permeability mainly depends upon the size of interconnected pores, which present in pervious concrete. Table 8 shows that for Mix M1, M2 and M3 there was a gradual decrease in value of permeability. Mix M4 shows that when compared to the other mixes permeability value was very low which depends on angularity number of the aggregate which also proved the same. It is evident that the permeability results were consistent with the angularity number. Angularity number and permeability are highly correlated. Permeability depends upon the effects of aggregate sizes as well as the effects of addition of fine aggregate. Permeability increases with the use of large size aggregate. However, permeability decreases with increase in sand content. It is evident from the Table 8 that permeability values for all the mixes range between 0.401cm/sec to 1.258 cm/sec which is sufficient enough for a drainage layer for pavement.

Permeability reductions of various mixes with the corresponding sizes are presented in Table 8. Comparing M1 to M2 percentage reduction in permeability it is 6%, M2 and M3 percentage reduction it is 7.45% when comparing with M3 and M4 percentage reduction it is 17% without fine aggregate. Decrease in the angularity number result in reduction of permeability. Decrease in permeability of about 5% for M1 and M2, for the mixes of M2 and M3 it is 7.8% and for M3 and M4 it is very high at 26%. Mixes with and without fine aggregate were observed the same trend with reference to angularity number.

Table 8. Results of permeability of pervious concrete

Percentage of fine	Permeability(cm/s)			
	M1	M2	M3	M4
F0	1.258	1.182	1.094	0.907
F10	1.175	1.106	0.984	0.726
F20	1.096	1.029	0.940	0.705
F30	0.876	0.862	0.834	0.597
F40	0.771	0.741	0.671	0.480
F50	0.579	0.533	0.508	0.401

Table 9. Result of Tile Abrasion (Percentage of wear)

Percentage of fine	Tile Abrasion Resistance(% of wear)			
	M1	M2	M3	M4
F0	4	4.47	4.47	4.55
F10	4.23	4.92	4.93	4.74
F20	4.71	4.95	4.98	5.29
F30	4.96	5.68	5.58	5.88
F40	5.51	5.73	5.8	6.19
F50	5.73	6.19	5.96	6.67

3.4. Abrasion Resistance

Abrasion is an essential property of pavements. Abrasion resistance results obtained from the tile abrasion test are shown in Table 9. It showed that percentage of wear is more when the angularity number is reduced. This is attributed to larger contact mass between the specimen and the abrading surface, as the void present in these specimens is less comparable to the large size of aggregate. Percentage of wear varies from 4 % to 6.67%. However, it is observed that no meaningful correlation was observed between angularity number and the abrasion resistance.

3.5. Total void in aggregate and Permeability of pervious concrete

Fig 4 represents the relationship between total void in aggregate and coefficient of permeability of the pervious concrete. The void content increase the permeability of the pervious concrete and also it increases regardless of aggregate size and the percentage of fine aggregate. The coefficient of permeability increases exponentially with void content. The results signify the importance of void content present in aggregate and percentage of fine aggregate regardless of the size of aggregate and cement content.

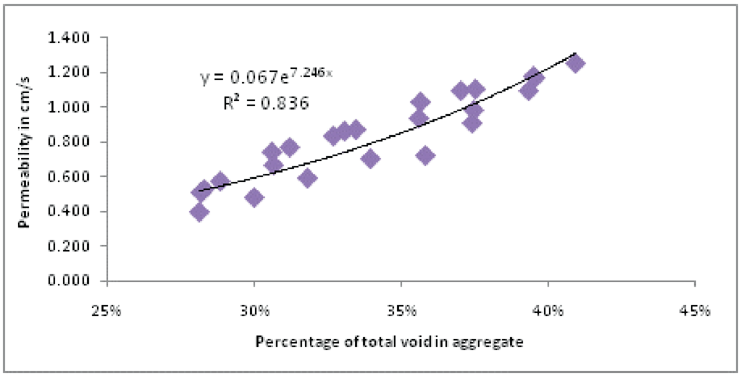

Fig.4. Effect of Total void in aggregate on Permeability

3.6. Total Void in aggregate and Strength characteristics

The relationship between total void present in aggregate to the compressive strength are shown in Fig.5. It shows that as void content increases compressive strength decreases. With the addition of percentage fine aggregate in the mix increases Compressive strength. Compressive strength varies from 9.6 N/mm^2 to 26.2 N/mm^2 irrespective of the size of aggregate and the influence of fine aggregate addition. Total void present in aggregate varies from 28.13% to 40.91%. It follows the general trend. There is a definite correlation between total void and compressive strength.

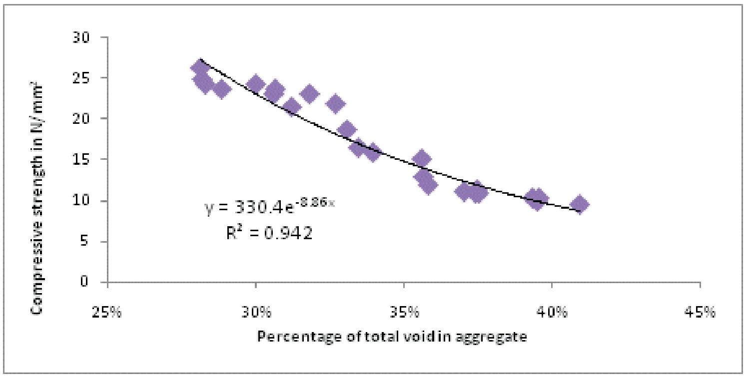

Fig.5. Effect of Total void in aggregate on Compressive Strength

3.7. Optimum Mix from Permeability and Compressive Strength

Fig.6 shows the relationship between the compressive strength, permeability with total void present in aggregate to determine the optimum mix. It shows that when the total void increases compressive strength decreases and permeability increases. Angularity number increases the total void present in the mix also increases. Influence of fine aggregate addition in the mix reduces the volume of voids by increasing the strength and decreasing the permeability value. Balancing the compressive strength and permeability, optimum mix is determined. Compressive strength found to be lying between 15N/mm^2 to 20 N/mm^2 and permeability between 0.6 cm/sec and 0.8 cm/sec. With reference to the above values the following mixes are identified as optimum M1F30, M2F30, M3F20 and M4F20.

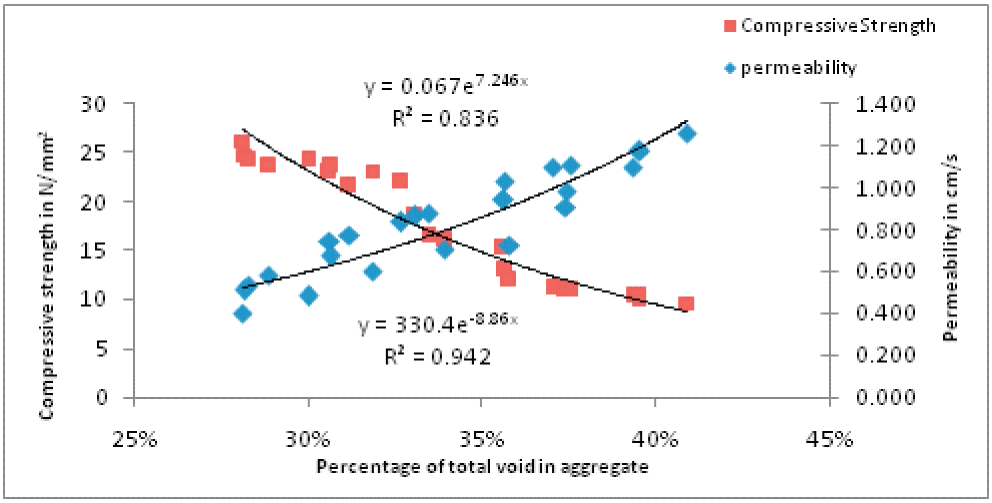

Fig.6. Optimization of mix based on total void in aggregate on compressive strength and permeability.

4. Conclusion

This study illustrates angularity number, which influence properties and behavior of pervious concrete with fine aggregate and coarse aggregates. It is observed that the increase in fine aggregate results in reduction of volume of voids which in turn increase of compressive strength, flexural strength and split tensile strength. Angularity number is more for higher size aggregate and which is reduced when size of aggregate reduces. The range of compressive strength varies between 10 N/mm^2 to 26 N/mm^2 when the angularity number varied from 8 to 4. Increasing the aggregate size increases angularity number. Coefficient of permeability increases from 0.4 cm/sec to 1.26 cm/sec when the angularity number is in the range of 4 to 8. The optimum mixes in each coarse aggregate size are identified based on the compressive strength, Void present in aggregate (based on angularity number) and permeability are M1F30, M2F30, M3F20 and M4F20. However, the influence of angularity number on the abrasion value of the pervious concrete could not be established.

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