

Experimental Investigation of Pervious Concrete using Recycled Crushed Aggregates

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ABSTRACT: Apart from the normal conventional concrete, pervious concrete is used around the world to drain the runoff from low traffic pavements and recharge the ground water, in parking lots, to filter the harmful minerals in water percolating through soil and many such. The major drawback of pervious concrete is its less strength and clogging of voids. After the building has been demolished, the aggregates can be reused as recycled aggregates. For Present work, instead of natural coarse aggregate, Recycled crushed aggregates (RCAs) have been used completely and an effort has been made to improve the properties of pervious concrete by replacing parts of recycled crushed coarse aggregate by M-sand. Pozzolanic Portland cement is used instead of Ordinary Portland cement. ACI method is adopted for the mix design of pervious concrete. In order to check the hardened properties, compressive and flexural strength is conducted. The porosity property of pervious concrete determined by the laboratory set up permeability apparatus. Instead of ordinary water immersion curing for 28 days, accelerated warm water curing technique is adopted. The M-sand is varied in 0%, 5%, 10% and 15% by weight of total aggregates. The mix with 15% M-sand and 0.7% superplasticizer (PCF3) shows better mechanical strength and lesser porosity due to filling up the voids when compared to other mix prepared.

KEYWORDS: Pervious concrete, Recycled crushed aggregates (RCAs), Accelerated curing method, Permeability

I. INTRODUCTION

Concrete is one of the important materials essentially used for the development of urban areas. Urbanization leads to the development of high-rise buildings, pavements, infrastructure etc., which majorly occupies the land surface. Whenever proper drainage facilities have not provided in congested areas, especially in the rainy season, the water will not have proper route for its discharge leading to the stagnation on surface of road. Due to the occupancy of building and compacted pavements on land surface, there may be decrease in rain water ingress leading to decrease in ground water recharge. One of the alternatives to drain off the water from such areas is the provision of pervious concrete.

Nowadays, due to scarcity of natural coarse aggregate, the need for the alternative is created. In recent years, due to increase in the cost of the landfill, the use of construction waste for the production of concrete has become a trend. Recycled aggregates can be used as an alternative to fill the coarse aggregate place from the construction and demolition waste. Recycled crushed aggregates (RCAs) from demolished buildings can make up to 75% of concrete. The recycling of concrete is nothing but breaking, removing, crushing and grounding the existing concrete to the specified size and quality. The enormous quantity of demolished aggregates can be used without processing in the places like bank protection, bulk fills, drainage structures, embankments, noise barriers, road works etc. [1]. The best and economical way for the use RCAs will be its use in the porous concrete design. The use of RCAs in pervious concrete increases the absorption capacity. Hence, it helps in reducing the stagnation of water on the surface. Along with that, M-sand is can increase the efficiency of absorption of water.

The pervious concrete is a special type of concrete meant for the particular applications like in storm water management in the urban areas. The pervious concrete contains binder (cement), coarse aggregate, water with no or little fine aggregates (and additives can be used to boost its properties). For a pervious concrete, the important thing is its permeability property. Unlike conventional concrete, which has a void ratio anywhere from 3-5%, pervious concrete can have voids ratio from 15-30%. As it meant to allow the water to drain off from the surface, it's called as permeable or porous concrete. The design of it should be such that, it should have proper highly interconnected voids. The pervious concrete are mainly applied in low volume pavements (like in base course), drainage structures, sidewalks, residential roads, parking lots, in slope stabilization, pool decks, noise barriers etc. There are many environmental benefits of pervious concrete such as retain storm water, recharge ground water, keep pavement surfaces dry even in wet situation, reduce or no storm water drainage is required, alleviating the precipitation load on overstressed drainage systems [2], allow water and air to get to the roots of trees in the area, remove oil and other pollutions from the that washes off the surface, reduce heat island effect(water percolating through the pavement can exert a cooling effect through evaporation and convective air flow can also contribute to cooling, reduction in standing water on pavements,

and reduced tire pavement noise emission). With high level of permeability pervious concrete can effectively capture the first flush of rainfall (the part of the run-off with a higher contaminant concentration) and allow it to percolate into the ground where it is filtered and treated through soil chemistry and biology.

The main complaint about the use of pervious concrete is its lesser mechanical strength. Due to which, the application of it is restricted in the high traffic pavements. As it's porous in nature, the rain water can carry small unwanted particles, creating clogging problems [3]. Clogging makes the concrete maintenance costly and decreased infiltration rate.

II. RELATED WORK

In order to overcome these problems and for the betterment of pervious concrete properties using recycled aggregates, many researchers around the world are working, here are some of the literatures regarding that, Yang and Jiang investigated the effect of compaction energy on pervious concrete, void ratio, compressive strength, tensile strength, unit weight, and freeze- thaw durability. Bakshi et al. have designed the pervious concrete with 15% voids in order to check the mechanical properties and infiltration rate. Pitroda et al. have examined the mechanical properties by replacing hypo sludge and suggested recommended using hypo sludge in concrete to save the paper industry waste disposal costs inspite of getting lesser strength than the traditional pervious concrete. Nguyen and Khan investigated with 20%, 40% and 60% seashell by-products as coarse aggregate in place of normal one and 40% replacement of it showed better strength and permeability properties. The addition of sand and short fibres can be used to optimize the strength, porosity, freeze thaw resistance properties of porous concrete [8]. Yap et al. blended the natural and recycled coarse aggregate in order to analyse the greenhouse gases assessment of pervious concrete. Sriravindrarajah et al. used ground granulated blast furnace slag up to 70% by weight of cement and RCAs for the preparation of pervious concrete for the examination of strength and porosity properties and concluded that water permeability of pervious concrete is primarily influenced by the porosity and not affected by the use of recycled concrete aggregate. Sharma et al. investigated the effects of different cement to coarse aggregate ratio and added different percentages of fine aggregate for pervious concrete and the mix with 10% fine aggregate with 1:4 c/a ratio showed them an enhanced mechanical properties. The clogging potential and abrasion resistance had been investigated by Hassan et al. along with the void content, porosity and other mechanical properties by using RCAs and slags in the porous concrete. The clogging problem of porous concrete or permeability can be restored to acceptable range through pressurized water washing [12]. Permeability co-efficient of porous concrete with polypropylene thick fibre was observed to be better when compared with polypropylene and copper coated steel fibre with recycled aggregates [13]. As the usage of recycled aggregates may give lesser mechanical properties to the concrete, Liu et al. have used silane polymer emulsion treatment to enhance the strength and permeability properties of RCAs incorporated pervious concrete. As concerned to the waste utilization, Lori et al. have used the copper slag aggregates replacing dolomite coarse aggregates in the porous concrete preparation and they achieved greater permeability properties including copper slag aggregates. As the voids are not filled in case of pervious concrete, it's light in nature and considered to be light weight concrete due to which it has properties like lesser density and drying shrinkages. Aliabdo et al. used recycled coarse aggregates in 50% and 100% by weight of natural one with aggregate size varying 9.5mm & 19mm and investigated with fibre rubber, polypropylene fiber, silica fume and styrene butadiene latex as a property enhancer to enhance the strength indices of pervious concrete. Styrene butadiene rubber based polymer powder and latex were used by Bhutta et al. in order to improve strength properties and compared the pervious concrete properties by incorporating recycled aggregates and natural coarse aggregates. By increasing w/c from 0.25 to 0.30 and replacement ratio of RCAs, Zhang and Gao obtained conclusion that void content and permeability increased but compressive, splitting and abrasion resistance shows downward trend. The pervious concrete may be subjected to impact loads when they used as pavement materials. Savithri et al. designed the pervious concrete with cement partially replaced by the ground granulated blast furnace slag and adding recronfibers and fine aggregates as strength improving material, drop ball method was used by them to check the impact strength of designed porous concrete.

In the present investigation, pervious concrete is designed by ACI method. In order to utilize the demolition waste, the recycled crushed aggregates have been used instead of natural coarse aggregate, as waste utilization; fly ash based Pozzolanic Portland Cement used instead of ordinary one. The M-sand and sulphonated based superplasticizer are used to examine in order to overcome the strength back sets of pervious concrete. Instead of any bond aiding compound, superplasticizer is used to create the bond between cement particles. Along with that accelerated warm water curing technique is used instead of 28 days water immersion curing method to avoid such time lag. The fresh properties of superplasticizer induced pervious concrete have been conducted. The compressive strength, flexural strength and porosity properties of casted pervious concrete is explained in upcoming paragraphs.

III. METHODOLOGY

A. MATERIALS

The materials used for the investigation are cement, recycled coarse aggregate, river sand, water and superplasticizer. As a binder material, Pozzolanic Portland Cement (PPC) conforming to IS: 1489 (Part 1)-1991 is used. It was procured from a reputed cement company and guaranteed with chemical composition. The basic test results of PPC have shown in table I.

TABLE I. PHYSICAL PROPERTIES OF PORTLAND POZZOLANA CEMENT

Sl. No	Tests	Results	Test Methods
1	Specific gravity by Le-Chatelier's flask	3.15	IS 4031 (Part 11)-1988
2	Fineness test by 90 μ sieve method	Less than 1%	IS 4031 (Part 1)-1996
3	Standard consistency	33%	IS 4031 (Part 4)-1988
4	Initial setting time	95 min	IS 4031 (Part 5)-1988
5	Final setting time	355 min	IS 4031 (Part 5)-1988

Coarse aggregate used in the investigation is Recycled Crushed Aggregates (RCA) instead of natural granite aggregates. RCAs used are conforming to IS: 383-2016. The RCAs used are Surface moisture dry and basically angular or flaky in nature (which is suitable for porous concrete). The RCAs are brought from demolition work taken place at college premises and they are crushed in abrasion machine and manually to some extent. As we require voids, 16mm down and 12.5mm retained coarse aggregates were used. The physical properties of RCAs have been shown in table II.

TABLE II. PHYSICAL PROPERTIES OF RECYCLED CRUSHED AGGREGATES

Sl. No	Tests	Results	Test Methods
1	Specific Gravity by Pycnometer method	2.45	IS 2386 (Part 3)-1963
2	Water absorption by oven dry method	3.4%	IS 2386 (Part 3)-1963
3	Fineness modulus by sieve analysis method	8.05	-
4	Aggregate impact value	28.75%	IS 2386 (Part 4)-1963
5	Los Angeles Abrasion Value	30.30%	

In order to increase the strength of pervious concrete, fine aggregates were used. Manufactured sand (M-sand) was used instead of natural river sand and procured from Oriental granites and crushers, Karkala. The grading chart is shown in Chart I and conforming to zone II of IS 383-2016 with fineness modulus of 2.49. The basic test results of M-sand have been shown in table III.

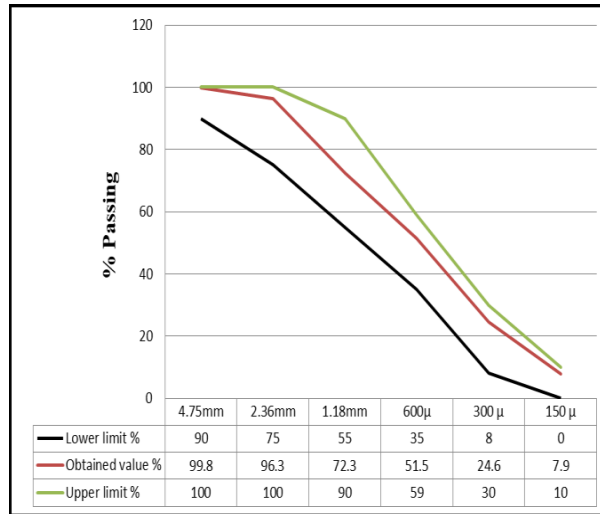


Chart 1. Gradation chart of Manufactured-sand

TABLE III. BASIC TEST RESULTS OF M-SAND

Sl. No	Tests	Results	Test Methods
1	Specific Gravity by Pycnometer method	2.63	IS 2386 (Part 3) 1963
2	Water absorption by oven method	1.626%	

Water used is a potable one and free from harmful impurities conforming to BIS used to prepare mixes and for curing purpose. Superplasticizer used as a water reducing agent and to enhance bonding properties. Superplasticizer used is Conplast SP430 DIS procured from Fosroc Chemicals India Pvt. Ltd conforms to IS: 9103-1999. The superplasticizer used is a brown liquid based on Sulphonated naphthalene polymers with specific gravity 1.25.



Fig. 1. An image of superplasticizer sample used

B. MIX PROPORTION

The mix design for porous concrete was done based on American Concrete Institute method (ACI 211-91). For preparation of porous concrete, the stiff mix is preferred. Initially normal conventional porous concrete (PC0) and porous concrete with superplasticizer and without M-sand (PCF0) are designed. Later by fixing the superplasticizer dosage and to improve the mechanical properties, the parts of recycled crushed aggregates are replaced by M-sand. The M-sand replaced in 5%, 10% and 15% by weight of RCAs. We have named the specimens like PCF1, PCF2, and PCF3 for 5%, 10% and 15% M-sand respectively. As per ACI method, the w/c ratio is taken as 0.35. After conducting many trails, the dosage of superplasticizer is fixed as 0.7% by weight of cement. The aggregate-cement ratio (a/c) is obtained as 1:4.3. The mix proportions have been shown in Table IV. The total % voids obtained for PC0 specimen as 15.12% as per mix design. The care is needed while compacting the specimen.

TABLE IV. MIX PROPORTION OF TESTED SPECIMENS

Mix name	Addition of M-sand % by weight of RCAs	PPC in kg/m ³	Water in kg/m ³	RCAs in kg/m ³	M-sand in kg/m ³	Conplast SP in kg/m ³
PC0	0	345	120	1485	0	0
PCF0	0	345	120	1485	0	2.4
PCF1	5	345	120	1444	75	2.4
PCF2	10	345	120	1368	149	2.4
PCF3	15	345	120	1292	223	2.4



Fig. 2. Ingredients to make pervious concrete using RCAs

C. TESTS AND SPECIMEN DETAILS

The ingredients were weighed as per obtained design and dry mixed initially. The water is added once the homogeneous mix is obtained and mixed thoroughly. The stiff mix obtained is checked for fresh properties by slump test. The consistency check is performed as per IS: 1199-1959. In order to check the hardened properties of pervious concrete, the compressive strength test and modulus of rigidity test were conducted. A minimum of 3 specimens were casted for each mix as shown in fig. 3 and accelerated curing method is used for curing and to accelerate the strength gain. For examining the compressive strength 100mmx100mmx100mm cubes were casted and cured. The compressive stress was applied at the constant rate until the specimen failed. The flexural strength of the specimens was tested by casting 100mmx100mmx500mm prism using symmetrical two-point loading. The hardened properties were tested based on the IS: 516-1959.



Fig. 3. Casting of specimens before placing it into curing tank

Accelerated curing is a time and cost saving method, instead of waiting for 28 days, the strength gain can be achieved in 24hrs. The procedure followed for Warm water accelerated curing would be as per IS: 9013-1978. Once the mix is placed in cubes, its allowed as it is without vibrating for atleast 3-4hrs. The warm water in accelerated curing tank should be maintained between 55°C and 65°C. The specimens placed in tank covered with plate as shown in fig.4

and allowed for at that temperature for 24 hrs (in between 14hrs and 34hrs). Later, its cooled for some duration not less than 1hr. The specimen cured is allowed for different testings.

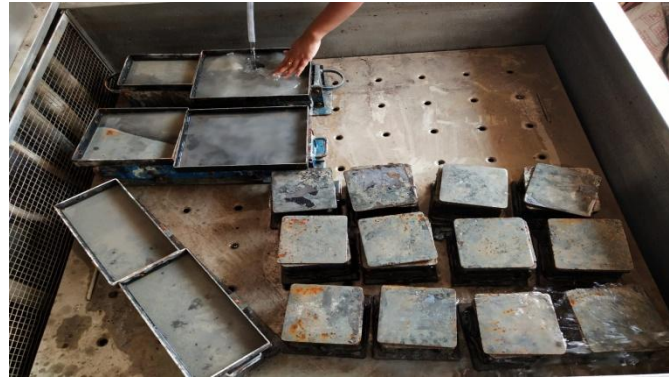


Fig. 4. Accelerated warm curing technique

The most important criteria for pervious concrete is its permeability or porosity property. The cubes of 100mmx100mmx100mm were used and accelerated curing is adopted for curing. The permeability set up was made at laboratory as shown in fig.5. The constant head method permeability is adopted. Adjust the hydraulic head by controlling the inflow, water is continuously passed through the porous concrete at a constant head for some duration. Water is passed in such way that it covers overall surface of concrete. The discharge rate is noted down and permeability value is determined using the equation (1)

$$k = \frac{qL}{Ah} \dots\dots(1)$$

Where, k= Co-efficient of permeability

q= Discharge

L= Length of specimen

A= Cross sectional area specimen

H=Constant head causing flow



Fig. 5. Permeability test apparatus



IV. EXPERIMENTAL RESULTS AND DISCUSSION

A. Fresh Properties test

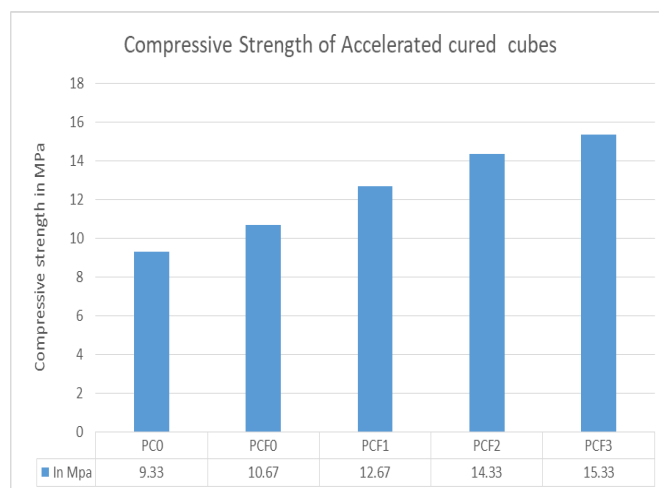
The slump test had been conducted in order to check the consistency of the mix and to fix the superplasticizer dosage. Usually the porous concrete is designed as a stiff mix due to its less w/c. The superplasticizer varied in 0%, 0.5%, 0.6%, 0.7% and 0.8% by weight of cement. The slump cone test results shown in table V. As the porous concrete does not require much workability, the mix with 0.7% of superplasticizer with slump value of 15mm is selected for further investigation. The effect of RCAs on workability was neutral as its constant for all the mixes. The variation of superplasticizer dosage doesn't give much of workability changes as we seen in table V.

TABLE V. SLUMP TEST RESULT

% of superplasticizer by weight of cement	Slump value in mm
0%	0
0.5%	6
0.6%	10
0.7%	15
0.8%	20

B. Compressive strength test

Pervious concrete's compressive strength has been checked by applying compressive loads over the accelerated cured cubes. The graph 1 shows linearly increasing trend of strength gain. The addition of superplasticizer increased the bearing capacity of casted cubes under the compressive loads with 15% increase. The PCF0 specimen shows increase in strength after adding sulphonated superplasticizer when compared to PC0 specimen by 14%. This may be due to the molecular re-arrangement and enhancement of bond strength. The graph also shows that the addition of M-sand gives an increment in the compressive strength. The specimen PCF3 specimen shows 63% increase in compressive strength than the PC0 specimen. The graph shows upward trend due to the voids filling action by the added fine aggregates. Fine aggregates are added mainly to fill up the voids between the coarse aggregates. Whenever the voids are there in concrete volume, the load applied will not pass through that voids and specimen get damages very quickly. In spite of using recycled coarse aggregates, the compressive strength obtained is considerable with concern to cement content used. The accelerated curing may also a plus point for obtaining such strength of pervious concrete designed. The superplasticizer used helps in proper dispersion of cement particles to achieve proper bond without forming clusters.



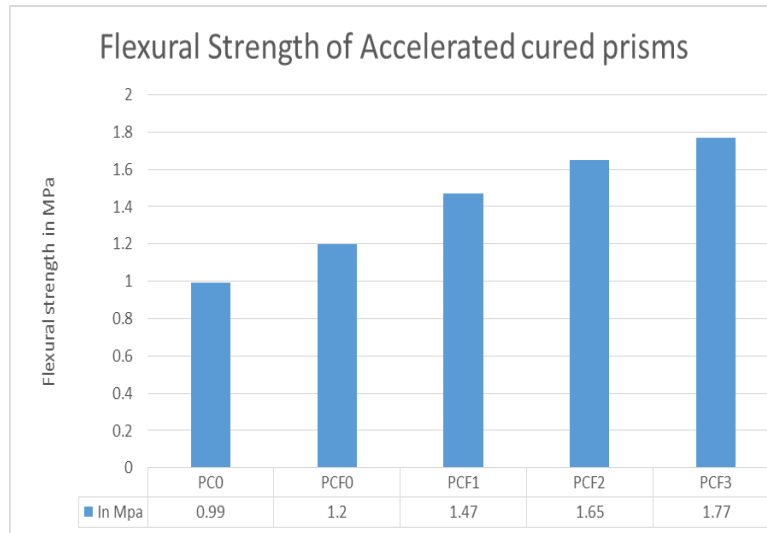
Graph 1. Compressive strength test result

C. FLEXURAL TEST

The prisms have been used to test the flexural strength of specimens. The results are depicted in the graph 2. The graph shows an increasing trend as we increase the fine aggregate content. The PCF0 specimen (0.7% superplasticizer) shows an increase of 20% than the PC0 specimen. This shows that due there is an impact of superplasticizer on improvement of strength. This is because of the increase in bonding between the cement particles. The addition of M-



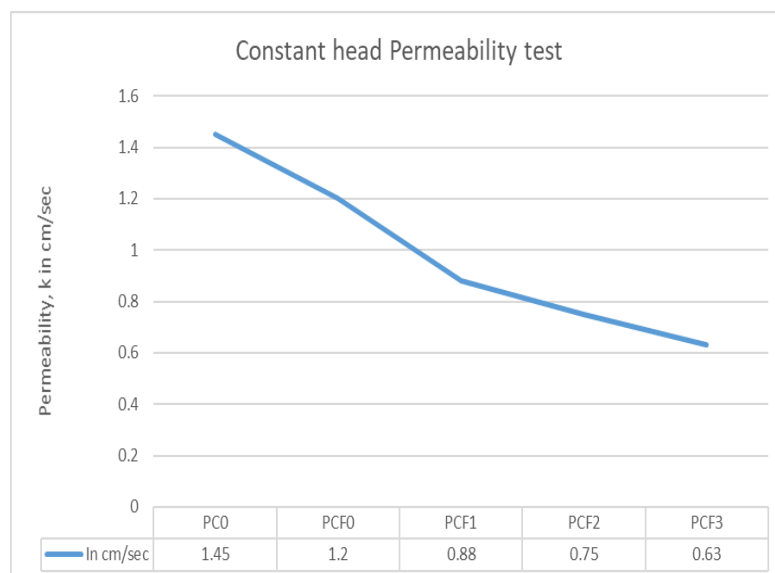
sand shows a linearly increasing graph because of voids filling action done by them. The mix with the 15% M-sand and 0.7% superplasticizer (PCF3) shows a greater flexural strength than other specimens prepared.



Graph 2. Flexural strength test result

D. PERMEABILITY TEST

The most important property for a pervious concrete is its permeability property. In order to make the concrete permeable, the gap or voids between the coarse aggregate and cement matrix is essential. The permeability test of prepared pervious concrete cubes is done by constant head method. In this method, the water level in the tube is maintained constant level throughout testing and run the water for particular duration to check the water draining capacity of specimens. The test results have been shown in the graph 3. The specimen PC0 shows the highest water draining capacity than other specimen. The specimen with highest fine aggregate content, PCF3 shows the least permeability value. This is mainly because the voids ratio in the specimen PCF3 is very much less than the PC0 specimen.



Graph 3. Permeability test result

The voids in PCF3 specimen is partially filled with the M-sand particles, because of the water draining time is more and along with that it has more stress resisting capacity when compared to other specimens. The values achieved are sufficient for the draining the runoff through pavement or parking lots and also usage of recycled aggregates has absorption capacity helping to decrease the water level on the pavement.

V. CONCLUSION

As a solution to drain the rain water standing or flowing on the low traffic pavements and parking lots, the pervious concrete is designed. By minimizing the runoff to greater extent, the ground water can be recharged sufficiently in urban areas. Usage of recycled aggregates in pervious concrete increases the water absorption capacity. The experimental investigation shows the following conclusions,

1. The addition of M-sand and sulphonated based superplasticizer makes the pervious concrete stronger than the conventional pervious concrete. The PCF3 gives the highest compressive strength than all the specimens prepared.
2. There was also an improvement in flexural strength when fine aggregates used in the pervious concrete mix.
3. The use of warm water accelerated curing is a time saving one and there is no need to wait for the concrete to attain the strength for 28 days.
4. The permeability test result shows that the conventional (PC0) shows better water draining capacity than superplasticizer and M-sand incorporated specimens.
5. As the M-sand dosage increases, the stress-bearing capacity of the pervious concrete increases and the water draining capacity of the concrete decreases due to the gap filling process between the recycled aggregates.
6. Usage of recycled crushed aggregates in pervious concrete leads to utilization of demolition waste and encouragement of construction waste management as its not deemed fit for conventional fresh concrete.

VI. FUTURE WORK

Study can be made by adding different pozzolans and fibers as concern to improve the strength. Other waste materials and by-products can be used in the place coarse aggregates and fine aggregates as a resource utilization technique for the design of pervious concrete. The work carried extended by casting the specimen for the durability tests for different application.

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