Investigation of the Mechanical Attributes of Porous Concrete and its Performance Analysis Using Superplasticizers

Umer Zada[1], Hamid Ullah[2], Abdul Rehman Ghumman[3], Murad Khan[4], Muhammad Haris Javed[5], Muhammad Usman Ghani[6]

[1]Isra University, Hyderabad, Pakistan; E-mail: umerzada99@yahoo.com

[2] Shandong Normal University, Shandong, China; E-mail: engr.hamidullahgeo@gmail.com

[3] University of Engineering and Technology (UET), Taxila, Pakistan; E-mail: abdul.rehmanghuman@students.uettaxila.edu.pk

[4]School of Civil Engineering, Tianjin University, Tianjin, China E-mail: engrmurad2019@gmail.com

[5] Missouri University of Science and Technology, Rolla, USA E-mail: harisjaved055@gmail.com

[6] Wroclaw University of Science and Technology, Wroclaw, Poland E-mail: muhammad.ghani@pwr.edu.pl

Abstracts: Pervious concrete is a mixture of binding material, aggregate, water, and admixture. The water content plays an important role in the performance of the pervious concrete. When the water content is reduced, the density of the pervious concrete mix increases. The increased density also increases the strength, the weathering resistance increases, and permeability decreases, for wetting and drying the variations of volume decrease, and shrinkage cracking abilities also decrease. This experimental study was carried out to find out the optimum percentage of locally available superplasticizers on the workability and compressive strength of Pervious concrete and to compare the results of Pervious concrete with conventional concrete. Three different percentages of superplasticizer were utilized, with dosage ranging from 1% to 2% with an increment of 0.5%. The water-cement ratio remained constant at 0.25 for all pervious concrete samples. Based upon the results, all three percentages of superplasticizer increased the workability and compressive strength of Pervious concrete. The optimum dosage of super plasticizer was determined to be 1.5% which provided the maximum compressive. The pervious concrete can be used in low-volume traffic. The strength of pervious concrete can be increased by using high-performance cement and superplasticizers.

Keywords: Concrete, Aggregate, Super Plasticizer, Strength, Infiltration.

1. INTRODUCTION

Nowadays, urbanization is growing rapidly in Pakistan, and this urbanization is causing the key issue of precipitation flooding. In the city, much of the rainfall is transformed into runoff due to the impervious strata of the pavement [1-2]. Pervious concrete is used to overcome this threat by appropriate concrete. Pervious concrete also known as porous, permeable, or no-fines concrete consists of binding materials, coarse aggregates, admixtures, and water [3-5]. It is distinct from normal concrete because the mixture does not contain a fine aggregate. The aggregate is typically of one size and is bound by a paste of cement, admixture, and water at its points of contact. This combination, when cured, results in a concrete that enables a quick percolation of waterwith a high percentage of interconnected voids [6-7]. The pervious concrete has a void ratio of between 15% to 35%, on the other hand, conventional concrete has a void ratio of around 3% to 5%. Porous concrete requires high porosity to obtain maximum water permeability, but excessive porosity can lead to a significant loss in strength [8-10]. Porous concrete is a permeable concrete that allows water and air to pass through it. The mechanical characteristics of porous concrete often refer to the Compressive Strength, Flexural Strength, and Split Tensile Strength [11-12]. This research paper contains a thorough research and experimental study on Pervious concrete which mainly explains the compressive strength and permeability of porous concrete, in addition, with the above concrete materials a special durability admixture is used to increase the durability and strength of pervious concrete which is known as a superplasticizer.

The bond between the course aggregates is built by the binding material usually cement, the absence of fine aggregate causes the formation of voids around 15% to 35%. Generally, the water-cement ratio is one of the important factors for the compressive strength of cement concrete [14]. However, in the case of pervious concrete, the above concept may have little significance. Water is essential to produce fresh cement paste with good workability but not clog up all the pores. The optimum range of water cement ratio for both strength and permeability point of view ranges from 0.30 to 0.38. The porous concrete has the highest compressive strength of 10.3 N/mm2 by using the course aggregate size ranging from 9.0 to 12.5mm. Nowadays, the advanced version of water reducers has been introduced which is knownas super plasticizer. The superplasticizer is not a relatively innovation. However, since its development in the 1960s, its acceptance and utilization in the construction industry have gradually increased [15-17]. A study was carried out on the effect of superplasticizers on the behavior of porous concrete under different curing methods. ASTM C494 type A and F, anionic melamine polycondensate, a non-toxic superplasticizer was utilized. Four dosages of superplasticizer, ranging from 0.5% to 2% were added to the mixture with a constant water-cement ratio of 0.48. The specimens were cured under four different curing conditions. Based upon the results, it was found that 0.5% dosage is optimumin terms of enhancement of compressive strength. It was also observed that with the increase in superplasticizer dosage, the workability also increased. In another research it was concluded that the permeability and void content are directly proportional to each other as the void content increases permeability also increases and vice-versa. The average value of permeability ranged between 15 mm/sec and 24 mm/sec. The average compressive strength value was found to bearound 9 Mpa by using a 0.3 w/c ratio and 0% sand [18]. Porous or pervious concrete was used in about 1852. Porous concrete was initially started in Europe because of the cement crises. It is called Gap graded concrete in Europe. The current application of pervious concrete is as a paving material for the surface.

To make high-strength normal concrete we use coarse aggregates; fine aggregates; cement and water. But for making concrete pervious it is necessary to use minimum fine aggregate content or even avoid its use because they are used as void filling materials and they make concrete denser and compact, but in pervious concrete we need interconnecting voids to make the concrete permeable. Many experiments and research on pervious concrete as pavement materials are essential to use it more frequently in place of conventional pavement materials to reduce the bad environmental effects caused by normal pavements like drainage problems, groundwater depletion, and flood problems during excessive rain in urban areas wherea larger area of roads and pavements are covered with impervious nonabsorbing conventional pavements [19]. Pavements made with impervious conventional concrete offer greater strength and durability as they are compact in structure with void-filling fine aggregates and are more resistant to wear, tear, and impact loadings but they are incapable of providing proper drainage of water through them and thus do not help in flood problem in urban area caused due to excessive rain and poor drainage and do nothelp in reducing the load of water treatment plants [20]. Though the strength of porous concrete pavements is not as high as conventional concretes initially this porous concrete pavement was used only for light traffic foot and for house yard surfacing but with experiments on porou**s** concrete and wide awareness about its advantages over conventional concrete in the environment its use is made possible for further using it as traffic pavement materials and further experiments are going on to increase its strength. An experiment was conducted in which cement paste characteristics and pervious concrete properties were studied in the addition of a superplasticizer. The results indicate that cement paste characteristics were dependent on the water-to-cement ratio (W/C), admixture, and mixing time. Cement paste with highviscosity and high workability suitable for making pervious concrete was obtained with the use of low W/C of 0.20–0.25, incorporation of 1% superplasticizer, and sufficient mixing [21].

Another experimental study has been done the porous concrete using brick chips as coarse aggregate. The characteristics of porous concrete such as compressive strength, permeability, and void ratio were examined. Different sizes of aggregate were used here. Stone aggregates were also used here for comparison purposes. Relationships among various parameters including strength, void ratio, aggregate size, and permeability for two different porous concretes were also analyzed there. It was concluded that porous concrete made of brick chips performed well concerning permeability. However; the strength of this concrete is lower than that of the conventional aggregate concrete [22-23]. Brickaggregate can effectively be used as a coarse aggregate in porous concrete. From the experiment, it was found that the compressive strength of brick aggregate porous concrete is lower than that of natural aggregate concrete of the same aggregate size. However, the permeability of brick aggregate porous concrete is higher than stone aggregate porous concrete. Thus brick aggregate can be used in porous concrete in places where load is comparatively less and more permeability is required. A mixture of different sizes of brick aggregate may produce higher-strength concrete and, therefore; will increase its suitability and scope of applications.

Following is the objective of the research study.

To find an optimum dosage of superplasticizer (SP) and water-cement ratio to enhance the mechanical properties like compressive strength and permeability of pervious concrete, two properties which oppose each other. And the comparison of the achieved results of conventional concrete and pervious with and without superplasticizer.

2. MATERIALS AND METHODS

The concrete mix was prepared with different ranges of aggregate sizes and superplasticizer contents with aggregate sizes ranging from 9.5 mm to 12mm. A constant cement-to-aggregate ratio of 1:4 by weight was used for pervious concrete and a ratio of 1:2:4 by weight was used for conventional concrete. Then the pervious concrete specimens were prepared without fine contents using ordinary Portland cement as binding material andconventional concrete was made by using fine aggregate (sand). Three different percentages of SP were utilized in pervious concrete. The crushed stones were used which was provided by a local construction material shop. A size of 4" x 4" cubes was prepared by using gentle rodding. Tests for workability were performed during this process. A visual inspection was used to check the even coating of all the particles. Water curing was done for the samples, which was very important as there was a very small coating of cement paste around all the aggregate particles. The following tests were carried out: impact test of aggregates, compressive strength test on cube specimens, and infiltration test on the pervious concrete.

2.1. Aggregate Impact Test

The Impact Test of Aggregates has been performed to evaluate the toughness of the aggregates to breaking down under repeated application of impact. Aggregate impact value (AIV) indicates a relative measure of the resistance of aggregate to impact.

2.2. Mixture Proportion and Specimen Preparation

Porous concrete samples were prepared of different proportions adopting three differentranges of superplasticizer of 1%, 1.5%, and 2% with varying sizes of coarse aggregates ranging from 9.5 mm to 12 mm, three batches of porous concrete were prepared for each of three SP percentages. Using 1% of SP, three batches (1:4) were prepared and 9cubes were made per batch. Similarly, same number of cubes was made using 1.5% and 2% SP. Ordinary tap water was used for all samples; one batch was prepared for conventional concrete and one batch for pervious concrete without a superplasticizer.

2.3. Mixing Procedure

For pervious concrete a constant W/C ratio of 0.25 was adopted to minimize the water content and a 0.50 W/C ratio was used for conventional concrete. The measured proportions of the cement and aggregate were thoroughly mixed. The proposed amountof superplasticizer was added to the water and then that mixture was used in the dry mixed cement and aggregate to make pervious concrete. The mixing was done by handusing shovels in a tray with all the measured amounts of ingredients. The same procedure for mixing other batches and another percentage of SP was adopted.

2.4. Casting and Curing of Samples

After properly mixing the cement, aggregates, and water, the freshly prepared mix was placedin the molds in three layers with 25 times rodding and left for 48 hours to set in the mold. After 48 hours samples were taken out of the molds and cured. Three of the samples from each were tested after 7, 14, and 28 days to achieve compressive strength.

- The pervious and conventional concrete is filled in the cleaned and oiled cubemold and temped to achieve desirable compaction.
- The sample is left to set for two days and then the cubes are removed carefullyfrom the molds for curing.
- The pervious and conventional concrete cubes were cured in water for 7 days,14 days, and 28 days.

Figure 1: Fresh concrete and cast cubes

2.5. Experiments Performed and Observations

The tests that were performed on the concrete test samples are given in detail below;the tests are discussed with their results and a comparison is done for different SP percentagesas well as for conventional concrete and porous concrete without SP. For comparing results for different proportions of SP and conventional concrete, graphs are prepared along with the tabular data records. Various tests are as follows:

2.6. Compressive Strength Test

This test provides information about various parameters of concrete it gives an idea mainly about the strength that the structure is going to achieve in its service life and it gives an idea if the chosen percentage of SP, grade of concrete, and W/C is good for thestructure. The compressive strength of concrete is calculated by dividing the load applied by the cross-sectional area of the cube in which the load is being applied.

2.7. Infiltration Test

Infiltration test for pervious concrete conducted according to ASTM C1701. The test consists of four main components: Installing the infiltration ring, pre-wetting the concrete, testing the concrete, and calculating the results.

3. RESULTS AND DISCUSSION

In this section, all the results achieved after all the details of the investigation explained in previous sections are done. Take a step-by-step approach as identified in the sectionheadings below.

3.1. Compressive Strength

The experiment performed shows that the compressive strength is comparatively lower for porous concrete as compared to conventional concrete. The compressive strength of porous concrete for a given duration increases more significantly as compared to conventional concrete. Increasing in super plasticizer ratio increased the strength of the pervious concrete. For 7-days, compressive strength is highest for SP 1.5 % and lowest for SP 0%. For 14-days, again compressive strength is highest for SP 1.5% % and lowest for SP 0%. We have achieved a minimum compressive strength of 1308.3 psi and a maximum of 2403 psi for 28 days of curing. The compressive strength of pervious concrete without superplasticizer was achieved between 730.6 psi to 1026 psi. The compressive strength of conventional concrete achieved between 2718 psi to 2823.8 psi.

The overall average compressive strength however was lesser for porous concrete as compared to conventional concrete because of the absence of fine aggregate (sand) and higher porosity present in porous concrete. On the other hand, the compressive strength of pervious concrete increased significantly with the addition of a superplasticizer. The typical compressive strength values for pervious concrete are between 2.8 MPa to 28 MPa at 28 days as recommended by ACI. The strength of the tested sample falls between these recommended values and the strength is enough for drainage and walling materials.

The compressive strength tests were conducted on three samples from each mix. The results of the compressive tests are shown in Table. These results were observed after the compressive strength test of the samples after 7 days, 14 days, and 28 days of curing.

The given below table shows the variation of compressive strength for different percentages of superplasticizers.

Table 1: Compressive Strength values of the concrete

Sr. No	Samples with SP (%)	C/A	W/C	Compressive Strength (psi)		
				07 (days)	14 (days)	28 (days)
1	0	1:4	0.25	730.6	955.5	1026
2	1	1:4	0.25	908.7	1056.6	1308.3
3	1.5	1:4	0.25	1103	1708.5	2403
4	2	1:4	0.25	969.5	1708.5	2070.2
5	0 (Conv.)	1:2:4	0.5	2718	2796.6	2823.8

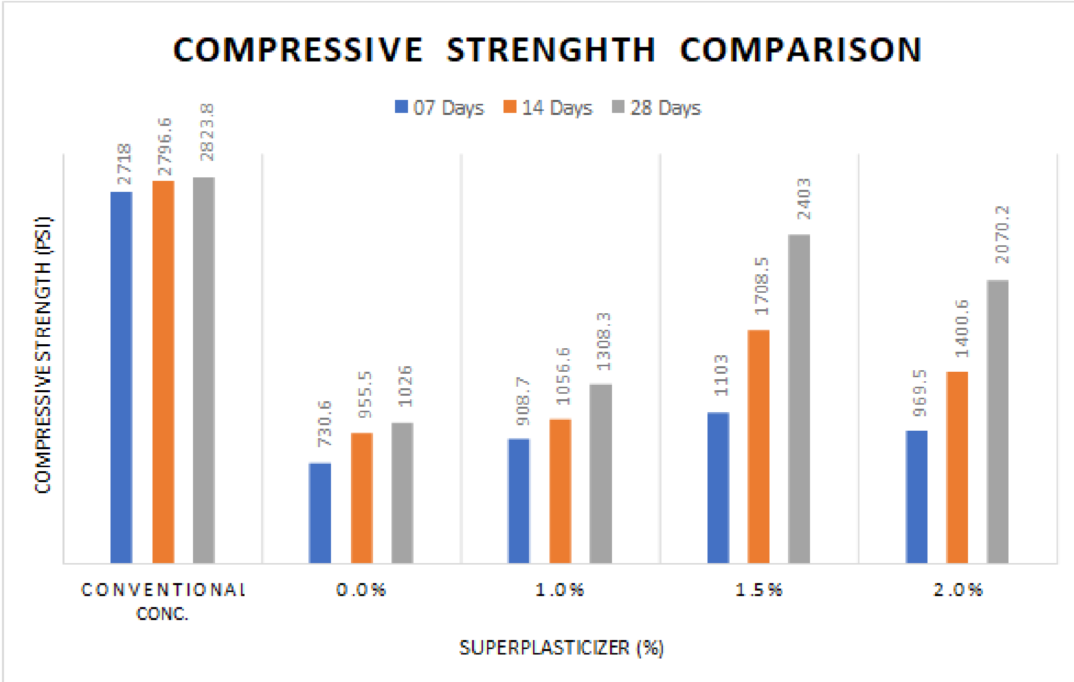

Figure 2: Compressive strength comparison values graph

3.2. Infiltration Test

The infiltration test on the pervious concrete was conducted after 24 days of curing. The experiment performed shows that the infiltration rate is maximum for the pervious concrete without superplasticizer and minimum for a sample containing 2% superplasticizer. The sample with 1% superplasticizer has an infiltration rate of 1358.8in/hr. If we increase the amount of super plasticizer to 1.5% the infiltration rate of pervious concrete decreases significantly.

Table 2: Infiltration Rate values

Sr. No	Samples SP (%)	Infiltration Rate (in/h)
1	0	1472.1
2	1	1358.8
3	1.5	1071
4	2	929.7

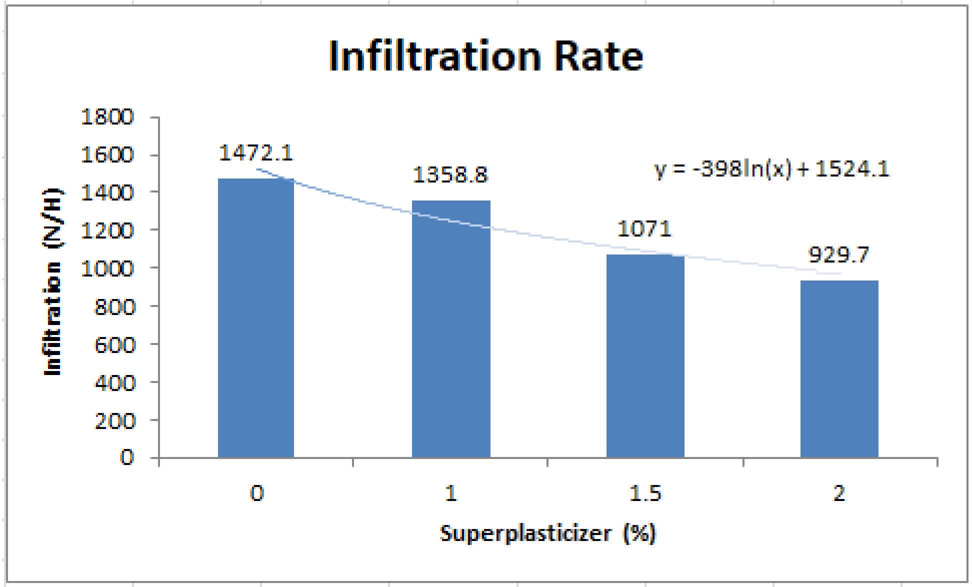

Figure 3: Infiltration rate values graph

3.3. Aggregate impact value test

Following are the results of the impact value test.

Table 3: Impact value test results

Sr. No.	Natural Aggregatevalue (%)	Average value (%)	Slate aggregate value (%)	Average value (%)
1	24.5	22.73	34	32
2	22.4		31.6	
3	21.3		30.4	

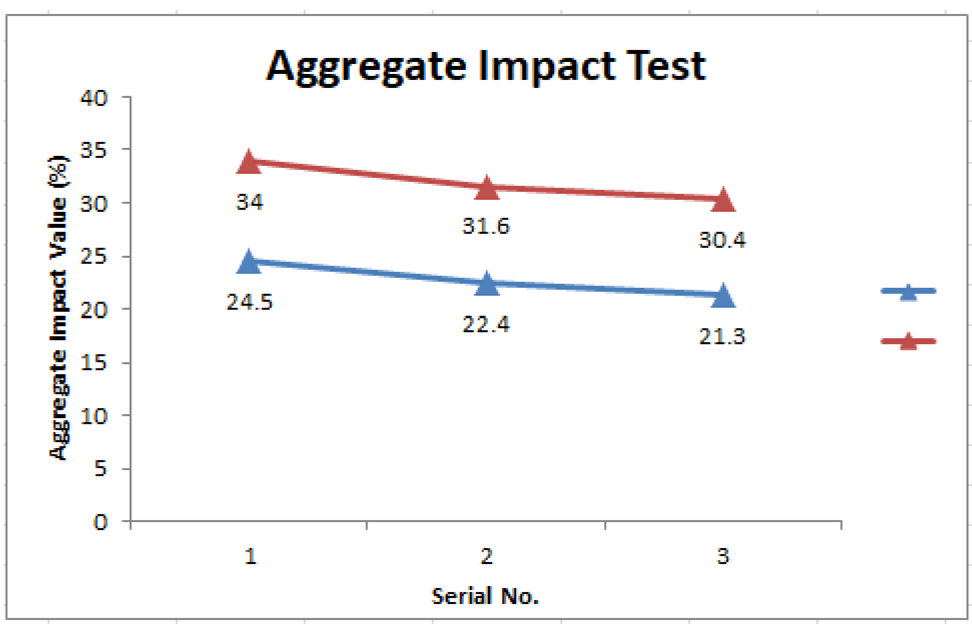

Figure 4: Aggregate impact test values of different samples

CONCLUSION AND RECOMMENDATIONS

- Following are the conclusion and recommendation points.

Conclusion

- By the observations of the results, it has been found that the compressive strength of pervious concrete with super plasticizer after 7 days 14 days, and 28 days of curing increased significantly with an increase in super plasticizer percentage.
- The compressive strength of the pervious concrete increased significantly with the addition of a superplasticizer.
- The compressive strength decreases with increasing porosity.
- This pervious concrete so prepared can be used for low-traffic areas like parking and where only foot traffic is allowed.
- The slump of pervious concrete increased with the increase of superplasticizer.
- Slump for pervious concrete is higher as compared to conventional.
- The density of porous concrete is less in comparison with conventional concrete because of fewer voids present in porous concrete. Hence it is good for lightweight concrete works.

Recommendations

- The aggregate sizes ranging from 9mm to 12.5mm should be used to getoptimum compressive strength and infiltration rate.
- The dosage of superplasticizer should not be increased from 2% since very highdosages of SP decrease the cohesiveness of concrete.
- Ultra-high-performance cement and superplasticizers can be used to get the desiredstrength.
- Freshly prepared pervious concrete containing superplasticizers should be placedimmediately since the initial setting time of concrete decreases.
- The casted cubes should not be removed from molds before 48 hours, as the samples containing superplasticizer do not dry within 24 hours.
- The surface of the pervious concrete should be swept regularly so that the watercan infiltrate easily.

Acknowledgment

First and foremost, we would like to thank our seniors who guided us in completing the work. They provided us with invaluable advice and helped us in difficult periods. Special thanks to Engr. Naheed as hermotivation contributed tremendously to the successful completion of the research. Besides, we would like to thank all the colleagues who helped us by giving advice and thanks to the University for providing the laboratory equipment. Also, we would like to thank our family and friends for their support. Without that support, we couldn't have succeeded.

REFERENCES

[1] Manandhar, B., Cui, S., Wang, L., & Shrestha, S. (2023). Urban flood hazard assessment and management practices in south asia: a review. Land, 12(3), 627.

[2] Bilgiç, E., & Baba, A. (2023). Effect of Urbanization on Water Resources: Challenges and Prospects. Groundwater in Arid and Semi-Arid Areas: Monitoring, Assessment, Modelling, and Management, 81-108.

[3] Vijayalakshmi, R. (2021). Recent Studies on the Properties of Pervious Concrete; A Sustainable Solution for Pavements and Water Treatment. Civil and Environmental Engineering Reports, 31(3), 54-84.

[4] Alimohammadi, V., Maghfouri, M., Nourmohammadi, D., Azarsa, P., Gupta, R., & Saberian, M. (2021). Stormwater runoff treatment using pervious concrete modified with various nanomaterials: A comprehensive review. Sustainability, 13(15), 8552.

[5] Debnath, B., & Sarkar, P. P. (2022). Application of nano SiO2 in pervious concrete pavement using waste bricks as coarse aggregate. Arabian Journal for Science and Engineering, 47(10), 12649-12669.

[6] Adresi, M., Yamani, A., Tabarestani, M. K., & Rooholamini, H. (2023). A comprehensive review on pervious concrete. Construction and Building Materials, 407, 133308.

[7] Nazeer, M., Kapoor, K., & Singh, S. P. (2020). Pervious concrete: a state-of-the-art review. Journal of Materials and Engineering Structures «JMES», 7(3), 417-437.

[8] AlShareedah, O., & Nassiri, S. (2021). Pervious concrete mixture optimization, physical, and mechanical properties and pavement design: A review. Journal of Cleaner Production, 288, 125095.

[9] Li, L. G., Feng, J. J., Zhu, J., Chu, S. H., & Kwan, A. K. H. (2021). Pervious concrete: Effects of porosity on permeability and strength. Magazine of Concrete Research, 73(2), 69-79.

[10] Debnath, B., & Sarkar, P. P. (2019). Permeability prediction and pore structure feature of pervious concrete using brick as aggregate. Construction and Building Materials, 213, 643-651.

[11] Seifeddine, K., Amziane, S., & Toussaint, E. (2022). State of the art on the mechanical properties of pervious concrete. European Journal of Environmental and Civil Engineering, 26(15), 7727-7755.

[12] Lamichhane, R., Motra, G. B., Khadka, T. B., Zhang, Y. X., Pathak, P., & Pandit, S. (2024). Impact of Water Level Variation on Mechanical Properties of Porous Concrete. Sustainability, 16(9), 3546.

[13] Kirthika, S. K., Singh, S. K., & Chourasia, A. (2020). Alternative fine aggregates in production of sustainable concrete-A review. Journal of cleaner production, 268, 122089.

[14] Lei, L., Hirata, T., & Plank, J. (2022). 40 years of PCE superplasticizers-History, current state-of-the-art and an outlook. Cement and Concrete Research, 157, 106826.

[15] Bezerra, U. T. (2016). Biopolymers with superplasticizer properties for concrete. In Biopolymers and Biotech Admixtures for Eco-Efficient Construction Materials (pp. 195-220). Woodhead Publishing.

[16] Jhatial, A. A., Sohu, S., Lakhiar, M. T., Shahzaib, J., & Buriro, A. A. (2018). Effectiveness of locally available superplasticizers on the workability and strength of concrete. Civil Engineering Journal, 4(12), 2919-2925.

[17] Carabba, L., Manzi, S., & Bignozzi, M. C. (2016). Superplasticizer addition to carbon fly ash geopolymers activated at room temperature. Materials, 9(7), 586.

[18] Tripathi, D. P. M., Hussain, S. A., & Madhav, P. (2017). An experimental study on pervious concrete (mix-ratio, strength and porous properties). Int. J. Eng. Res. Technol, 6, 100-103.

[19] Xie, N., Akin, M., & Shi, X. (2019). Permeable concrete pavements: A review of environmental benefits and durability. Journal of cleaner production, 210, 1605-1621.

[20] Rahman, S. (2015). Development of Durability Performance Related Test Methods for Pervious Concrete Pavement (Master's thesis, University of Waterloo).

[21] Supit, S. W., & Pandei, R. W. (2019). Effects of metakaolin on compressive strength and permeability properties of pervious cement concrete. J. Teknol, 81(5), 33-39.

[22] Debnath, B., & Sarkar, P. P. (2020). Characterization of pervious concrete using over burnt brick as coarse aggregate. Construction and Building Materials, 242, 118154.

[23] Manzur, T., Baten, B., Hasan, M. J., Akter, H., Tahsin, A., & Hossain, K. M. (2018). Corrosion behavior of concrete mixes with masonry chips as coarse aggregate. Construction and Building Materials, 185, 20-29.

DOI: https://doi.org/10.15379/ijmst.v11i1.3717