Taguchi Analysis of Pervious Concrete Mixtures: A Way to Increase Strength and Permeability

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Abstract:
A unique variety of concrete called pervious concrete is created by combining water, cement, and open-graded coarse particles. Usually, it contains very little to no fine aggregate concrete and only enough cement paste to coat the aggregate particles while preserving the interconnectedness of the spaces. The terms porous concrete, permeable concrete, no fines concrete, gap graded concrete, and improved porosity concrete are also used to describe pervious concrete. The experimental technique and findings for compressive strength, flexural strength, and permeability are presented in this work. Using Taguchi analysis, we were able to create an experiment with three variable factors—the mix proportion, the percentage of fine aggregates, and the percentage of human hairs as fibers—each with three levels. L9 arrays were utilized in this experiment. While varying the proportions of human hair as fibers of fine aggregate with coarse aggregates from 0.25%, 0.50%, and 0.75% of human hair of 0%, 5%, and 10% of fine aggregate accordingly in each proportion, the w/c ratio of 0.4 was used in this study. Whose findings show that the maximum compressive strength of M9 mix is between 1.45 and 3.48 N/mm2, the maximum flexural strength of M9 mix is between 0.135 and 2.11 N/mm2, and the maximum permeability of M8 mix is between 91.67 and 163.70 M/hr. That goes to show that adding more fibers helps to boost flexural strength, while adding more fine aggregates increases compressive strength at the same time.
Keywords: Pervious Concrete, Taguchi Analysis, Flexural Strength, Human Hair, Compressive Strength

Introduction:

The term "pervious concrete," also known as "porous concrete," "permeable concrete," or "gap-graded concrete," refers to a particular type of concrete composition. The absence or limited presence of fine particles, with the main ingredients being water, cement, and open-graded coarse aggregates, sets it apart from conventional concrete. Just enough cementitious paste is used in pervious concrete to coat the aggregate particles and preserve the structure's interconnecting spaces (Gray, 2013).

Concrete that is permeable or porous is known as pervious concrete and is a prime example of cutting-edge building materials. Due to its distinct qualities, it is becoming an increasingly attractive option for a variety of applications, especially in the context of ecologically friendly and sustainable construction. The management of stormwater runoff and its accompanying difficulties are of utmost importance as urbanization continues to alter landscapes and increase the amount of impervious surface area in cities.

Pervious concrete is fundamentally unique due to its composition. It has open-graded coarse aggregates in addition to a purposeful reduction in fine particles. This unique concrete mix design creates spaces that, when connected, allow water to permeate the surface and seep into the ground below. As a result, pervious concrete can greatly reduce stormwater runoff, lessen floods, and lessen erosion. This ground-breaking material demonstrates a variety of advantageous traits, including high porosity, which makes it possible for it to effectively regulate stormwater runoff, lessen floods, and reduce erosion (Aron, 2017). Additionally, pervious concrete helps to improve groundwater recharge, reduce the impact of the urban heat island, and support sustainable urban growth (Geosyntec, 2015).

This work includes a thorough analysis of important mechanical characteristics, including as compressive strength, flexural strength, and permeability, in an effort to better examine the characteristics and functionality of pervious concrete. The research methodically examines three important factors using a Taguchi experimental design: mix proportion, the percentage of fine aggregates, and the incorporation of human hairs as fibers. As a result of looking at each of these variables on three different levels, an organized matrix of experimental conditions is produced.

The impact of human hair fibers on the mechanical characteristics of pervious concrete is one of the study's main focuses. Between 0.25% and 0.75% of the total volume of fine aggregates are introduced to the mixture as human hair fibers, and the volume of fine aggregates is also altered. This reinforcement is readily available and sustainable. The water-to-cement (w/c) ratio used in the study is 0.4, which has a substantial effect on the performance of the concrete (Zhang et al., 2017). Pervious concrete is becoming more and more popular in the construction industry thanks to its unique features and environmental advantages, especially in the context of sustainable urban development. Its porosity, which permits water to pass through it, distinguishes it significantly from ordinary concrete. In order to minimize stormwater runoff and lessen the environmental issues brought on by urbanization, the concrete matrix's interconnecting voids function as conduits for water infiltration and percolation (Kevern et al., 2020).

The environmental benefits of pervious concrete are numerous. Traditional impermeable surfaces in cities usually result in rapid runoff, which leads to localized flooding, eroding land, and contaminating water sources, making stormwater management crucial. Pervious concrete's capacity to collect water and organically filter it provides a solution to these problems (Dewoolkar et al., 2013). Another important factor in lowering the urban heat island effect is pervious concrete. In highly populated urban environments, the prevalence of heat-absorbing surfaces contributes to rising temperatures, which can be harmful to the surrounding climate. With its capacity to both absorb and release water, pervious concrete helps to cool the environment, encouraging the creation of more livable and comfortable urban environments.

The advantages of pervious concrete also include groundwater recharging, which is important in areas where water scarcity and diminishing water tables are problems. Rainwater replenishes local groundwater supplies and promotes sustainable water management practices by penetrating the ground. The mechanical characteristics of pervious concrete are the main topic of this work, with a focus on permeability, flexural strength, and compressive strength in particular. It uses the Taguchi analysis methodology to methodically examine the effects of important variables. These parameters include the mix ratio, the proportion of fine particles, and the reinforcing using human hair fibers. In order to maximize pervious concrete's performance for different applications related to sustainable construction, the study aims to understand how variations in these elements influence the mechanical performance of pervious concrete (Ghosh et al., 2016).

Materials and Method:

As previously indicated, conventional concrete uses the same fundamental components as pervious concrete, but there are several noticeable differences. These modifications are made to achieve a high level of porosity, which efficiently allows water to infiltrate the substance. The main components and factors used in pervious concrete mixtures are broken down as follows:

Cement: Pervious concrete frequently uses Portland cement, just like regular concrete. To produce a desired permeability structure, the cement content is typically lower than in traditional mixes. The linked voids in the mixture are a result of the reduced cement content.

Coarse Aggregates: Coarse aggregates make up the majority of the materials in pervious concrete. These aggregates are chosen to have a particular size distribution that is kept fairly constrained. The linked gaps that distinguish pervious concrete are made possible by the tight size grading, which permits little particle packing. Crushed stone or gravel from nature often makes up the aggregates.

Water is utilized to make the cementitious paste that holds the coarse particles together. In order to maintain the necessary porosity while preserving the proper workability of the mixture, the water-cement ratio (w/c) is meticulously maintained. The w/c ratio for pervious concrete is frequently larger than it is for mixes of ordinary concrete.

Human Hair Fibers: Pervious concrete mixtures occasionally use human hair fibers as a reinforcing element. These fibers contribute to the material's increased flexural strength. An original method for enhancing the mechanical qualities of pervious concrete is to employ easily available and sustainable fibers like human hair.

Plasticizers: To make the concrete mixture more workable and fluid, plasticizers may be used. These ingredients can assist in producing a homogenous and consistent mixture that is portable and small.

Fly Ash Cement and Silica Fume: To improve the qualities of pervious concrete, additional cementitious materials like fly ash and silica fume can be used. These materials frequently result in increased strength, decreased permeability, and improved durability. By using waste materials, they also help the combination to be sustainable.

In contrast to the proportions and considerations employed in conventional concrete, these factors are somewhat different in pervious concrete mixes. To achieve the necessary porosity, strength, and permeability qualities, the suitable balance must be struck. In order for the mixture to be suitable for applications like pervious pavements, green infrastructure, and stormwater management systems, it is crucial to carefully control the mixture to ensure that it fulfills the project's specific performance criteria.

The Taguchi method calls for conducting exacting design experiments to reduce process variance. The main objective of the method is to produce high-quality product at the lowest cost to the producer. The Taguchi method was developed by Dr. Genichi Taguchi of Japan, who has since kept using it. Taguchi developed a method for designing experiments to investigate how different parameters affect the mean and variation of a process performance characteristic that shows how well the process is working. The process-influencing variables and the levels at which they should be changed are grouped in orthogonal arrays in Taguchi's experimental design. The Taguchi technique merely tests pairs of possibilities, whereas the factorial design needs testing every conceivable combination. This saves time and resources by reducing the number of trials necessary to gather the data needed to determine which factor most affects product quality. The Taguchi technique performs effectively when there are between three to fifty variables, there are few interactions between the variables, and just a few variables significantly contribute. So, to minimize the number of trials L9 array and three-level factors for cement to coarse aggregates ratio, fine aggregates and fibres were used as tabulated in Table 1.

Table 1. Mix Proportions with Levels

Level	Cement:Coarse Aggregates	Fine Aggregates (%)	Fibres (%)
1	1:6	5	0.25
2	1:7	10	0.50
3	1:8	15	0.75

Results and Discussion

The table 2 gives a summary of the various mix designs (M1 to M9) for pervious concrete, each of which has a distinct combination of components and ratios. In this discussion,

permeability, compressive strength, and flexural strength will be highlighted as we study the mix proportions and the accompanying test results.
The mixes, which have different material ratios, run from M1 to M9. The mix proportions are shown as a ratio, with cement represented by the first number and coarse aggregates by the second.

Table 2: Mix proportions and results

Mix id	Mix proportion	Cement(kg)	Fly ash (kg)	Silica Flume(kg)	FA (kg)	CA (kg)	Water(L)	Fibres (Human hair) (Gms)	Permeability In sec M/hr	Compressive Strength N/mm2	Flexural Strength N/mm2
M1	1:6	3.72	1.24	1.24	-	37.29	2.48	15.50	91.67	2.89	0.995
M2	1:6	3.72	1.24	1.24	1.86	35.42	2.48	31.07	104.17	3.41	0.135
M3	1:6	3.72	1.24	1.24	3.73	33.55	2.48	46.60	99.64	2.68	1.37
M4	1:7	3.26	1.08	1.080	-	38.06	2.17	13.59	91.67	2.38	0.212
M5	1:7	3.26	1.08	1.08	1.90	36.16	2.17	27.18	109.13	1.72	1.27
M6	1:7	3.26	1.08	1.08	3.80	34.25	2.17	40.78	104.17	3.08	1.8
M7	1:8	2.89	0.96	0.96	-	38.66	1.93	12.08	109.13	1.45	1.1
M8	1:8	2.89	0.96	0.96	1.93	36.73	1.93	24.16	163.70	3.28	1.40
M9	1:8	2.89	0.96	0.96	3.86	34.80	1.93	36.24	127.32	3.48	2.11

Fly ash and silica fume (mixes M1 to M3) appear to have a beneficial effect on compressive strength and permeability. The addition of these components improves the concrete's overall performance. Flexural strength is noticeably affected by human hair fibers, with mixes M9, M6, and M3 exhibiting the highest values. The qualities of the concrete are significantly influenced by the mix proportions. Depending on the proportions of cement, water, and aggregates employed, a concrete structure's permeability, compressive strength, and flexural strength may differ. The improved permeability and higher compressive and flexural strength ratings of mixtures M9, M6, and M3 indicate that they are more balanced materials. Comparatively speaking to the other mixes, Mixes M2, M5, and M8 exhibit moderate permeability and lower compressive and flexural strengths. The mixes M1, M4, and M7 have the lowest permeability, but they also have the lowest compressive and flexural strengths.

Conclusion:

The study has, in conclusion, shed important light on the mechanical and permeability characteristics of pervious concrete, revealing how particular mix proportions and variable elements affect its performance. The important conclusions and findings are as follows:

- The research shows the wide variety of compressive and flexural strengths that can be obtained with various mix amounts. Flexural strength ranged from 0.135 N/mm2 to 2.11 N/mm2, while compressive strength varied from a minimum of 1.45 N/mm2 to a maximum of 3.48 N/mm2. This broad spectrum emphasizes how sensitive these qualities are to modifications in mix design.
- The study also emphasizes the permeability's variety, with rates varying from 91.67 m/hr at the lowest to 163.70 m/hr at the highest. The ability of pervious concrete to allow water to move through and support sustainability in terms of stormwater management depends directly on its permeability, which is a crucial parameter.
- The findings show that, in comparison to other mix proportions, adding 10% fine aggregate to the M9 mix significantly increases both compressive and flexural strength. This result emphasizes how crucial fine aggregate content is for maximizing concrete strength.
- Mix proportions of M7, M8, and M9 consistently showed good compressive and flexural strength. These blend designs show potential for uses where strength is important.
- According to the study, adding 0.75 percent of human hair to a fiber improves flexural strength. This shows that adding fibers, like human hair, may help to enhance certain mechanical qualities. The results also suggest that additional increases in fiber content can maintain the enhancement of flexural strength.
- It was discovered that a higher proportion of fine aggregate in the mix improves compressive strength. This knowledge is crucial for mix design and offers suggestions for modifying pervious concrete to satisfy certain strength needs.

This study has given us a thorough understanding of the variables affecting the permeability and mechanical characteristics of pervious concrete. The information and conclusions offered here can help mix designs be optimized to reach target strength and permeability rates. This information is especially pertinent for applications like sustainable pavements and stormwater management systems where both structural performance and environmental considerations are important. These discoveries support continued attempts to create more effective and sustainable building materials as the field of concrete technology continues to advance.

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