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Optimizing pervious concrete pavement mixture design by using the Taguchi method

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HIGHLIGHTS

- The purpose of this study is to evaluate mechanical properties of previous concrete.
- Taguchi design of experiments was used to optimize the performance.
- Strength of previous concrete depends on total void ratio.
- The void ratio of specimens is slightly higher for larger size aggregates.
- The most influential control factors in compressive strength is the paste content.

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ABSTRACT

Pervious concrete is a sustainable pavement with high permeability. The purpose of this study is to evaluate physical and mechanical properties of the pervious concrete including density, strength, porosity, and permeability. Taguchi design of experiments was used to optimize the performance of these characteristics. The relationship between properties dependent on coarse aggregate size. As the maximum size of the coarse aggregate increases, both the permeability and porosity grows up. Also, it results in a significant decrease in compressive strength. There is a trade-off between strength and permeability which should be considered to meet the minimum requirements for the pervious concrete.

1. Introduction

"Pervious concrete" is a term that is applied to zero-slump material that allows water to infiltrate through it and be recharged as ground-water which consists of portland cement, coarse aggregate, little or no fine aggregate, water, and admixtures. These ingredients produce hardened concrete with connected voids.

Pervious concrete pavement (PCP) plays a substantial role in stormwater management and water quality control. Researchers have realized that runoff has potential to impact on surface and groundwater supplies. As urban regions are developed, impervious areas increase, which results in downstream flooding and bank erosion. Not only does PCP reduce the effect of land development by diminishing the runoff, it also protects water supplies [1]. Most importantly from a pavement engineers' perspective, having a reduced amount of runoff may improve the level of road safety [25]. Also, pervious concrete has several other beneficial specifications such as reducing noise, minimizing heat, protecting native ecosystems, recharging ground water, and protecting tree growth. Adequate pervious pavement infiltration can also reduce the need for sewer facilities. PCP may reduce the potential for legal problems for an owner or developer by reducing the need for stormwater ponds and subsequent safety [13].

Nowadays, many places around the world experience raining with ponding consequence. It is caused by combination of increased rainfall and reduced permeability in urban regions. To solve this problem, it is necessary to reduce various environmental problems occurring around residential regions. Different approaches can be used to meet achieving the new Environmental Protection Agency (EPA) standards. Urbanization significantly affects ground water recharge as runoff resulted from rainfall amplifies with imperviousness. Impervious surfaces need to be

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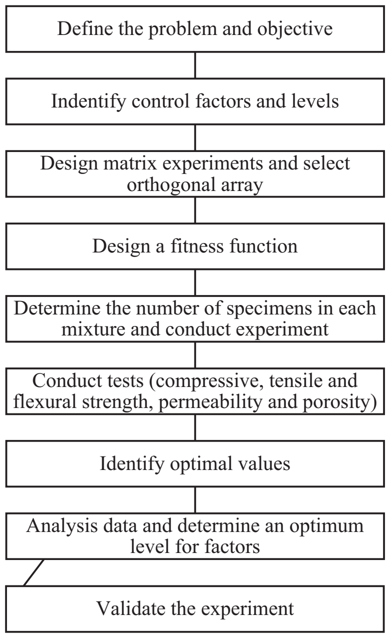

Fig. 1. Research methodology.

controlled to maintain the natural quality and quantity of recharge. Pervious concrete can keep natural hydrologic infiltration rates on developed lands. It is a sustainable technology and can be used for the low volume roads such as parking lots, driveways, and walkways. As the primary advantages of pervious concrete is its ability to rapidly infiltrate water, developing a suitable mix design for pervious concrete is essential before deploying this technology as an alternative pavement option. The major drawback of pervious concrete is its lower compressive, flexural strength, and clogging by fine materials compared to conventional concrete and cost of maintenance and cleaning is high for the pervious concrete [15]. By applying cleaning methods such as sweeping and pressure washing, little debris removed from the surface and the infiltration increase significantly [20]. The goal of this paper is to optimize pervious concrete mix design. The Taguchi method is utilized in order to determine optimal parameters for designing of pervious concrete pavement.

2. Literature review

Pervious road with course aggregate has 30–50% longer service life than normal pavement [14]. A single-sized aggregate gradation is commonly used to produce pervious concrete [26,23], which can easily achieve the required void content more than 15%. Too much sand and improper compaction energy may lead to an excessively low void content and reduced drainability features. Compaction and sand addition should be therefore analyzed more in details [7]. These mixture designs generally possess high permeability and inadequate strength [24]. A higher amount of small aggregate fractions (4–8 mm) yielded higher density concrete mixtures and greater flexural strength. However, connected porosity as a main parameter for estimating pervious concrete efficiency was surprisingly influenced more by the aggregate type than the size [10]. Increasing the cement paste area is another means of increasing the overall mixture strength [26]. This increase in cement paste area can easily be achieved through the use of smaller aggregates. With smaller aggregate, the cement paste will have more specific surface area to coat. Additionally, it has been examined that enhancing the cement paste itself can result in increased mixture strength [26]. In another research, water-to-cement ratios between 0.30 and 0.38 were tested, resulting in an optimal water to cement ratio of 0.32–0.34 [17]. The properties of the cement paste in pervious concrete vary largely from that of conventional concrete. Cement paste used in pervious concrete mixtures should have a high viscosity [8]. Further studies need to be conducted on the properties of cement paste used in producing pervious concrete. Another main concern with pervious mixture design is drain-down susceptibility. Researchers examined three different design void ratios of 15%, 20%, and 25% [8].

Through this information, it can be easily understood that there are many influential factors that affect the overall mixture performance, leading to both advantages and disadvantages of pervious concrete. When designing a pervious concrete mixture, factors such as aggregate gradation, paste contents, void percentage, and mixing methods must be considered.

3. Objective and scope

The objective of this study is to optimize the mixture design of pervious concrete pavement using the Taguchi method through evaluation of its physical and mechanical properties. Compressive, splitting-tensile, and flexural strength are tested to assess the mechanical properties of pervious concrete pavement. Three main control factors are utilized in the Taguchi methods including aggregate size, water-to-cement ratio, and percentage of cement paste.

4. Research methodology

After a detailed literature review, the next step is to define an objective for a performance measure of the process. In this study mechanical characteristics of pervious concrete are considered. The objective is maximizing strength and permeability rate. Then, the design parameters affecting the performance measure is assigned. Parameters are variables within the process that affect the measure. Three parameters were selected herein i.e., coarse aggregate size, water-to-cement ratio and percentage of cement paste (mass-based) that all can be easily controlled. After that, the number of levels at which the parameters should be varied is determine. Aggregate size range between 6.5–19.0 mm,

Table 1
Physical and chemical properties of the portland cement.

Physical properties								
Fineness (cm^2/gr)	Retained on sieve # 70 (%)	Autoclave expansion (%)	Normal consistency (%)	Setting time		Compressive strength (MPa)		Flow table
				Initial (minutes)	Final (minutes)	3-day	7-day	
2848	11.41	0.51	25.2	165	225	15.9	21.6	145
Chemical properties								
Components	Silicon Dioxide (SiO_2)	Aluminum Oxide (Al_2O_3)	Ferric Oxide (Fe_2O_3)	Calcium Oxide (CaO)				
Results obtained (%)	22.52	5.24	3.86	59.8				