STM JOURNALS

Recent Trends in Civil Engineering & Technology
ISSN: 2249-8753(online), ISSN: 2321-6476(print)
Volume 5, Issue 2
www.stmjournals.com

Pervious Concrete-A Tool for Sustainable Pavement Technology: A Review

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Abstract

Our planet earth is on its path to a deadlock due to its present-day development strategies. In the present scenario soaring pressure for the application of green technologies in developments to protect the nature from the adverse effects of construction industries have been endeavored by the goal of sustainable development and advancement in environmental management. Worldwide construction industries are geared towards Green concrete construction and sustainable development techniques. As a tool of sustainable techniques pervious concrete has a green future in many pavement applications. In the sustainable point of view the ability of percolating water and air through its composite makes no-fine concrete an adequate material for pavements to provide quick infiltration of rainwater and when it rains, it drains. This paper deals with various aspects of pervious concrete as a green product such as its composition properties and explores benefits like recharge ground water, minimize storm water runoff, provide air circulation to the soil, reduce heat island effect, and reduce pavement noise due to traffic and hence; develop a sustainable transportation environment. This review is an attempt to consolidate all information that relates pervious concrete as a tool for sustainable development. The paper can be a good reference for researchers working with pervious concrete and related Green Building technology. The usage of pervious concrete as a material in pavement can procure a valuable portfolio of environmental services by integrating green infrastructure systems in the design of sustainable landscapes.

Keywords: *Sustainable Development, Pervious Concrete, Rainwater Infiltration, Groundwater Recharge, Heat Island Effect*

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INTRODUCTION

The subsistence of future generation is under a high risk due to diminishing of natural resources, tremendous acceleration in energy requisition and environmental imbalance due to physical and chemical changes in nature. To face these backdrops, we have to concentrate on sustainable development and to widen our technologies to encourage efficient usage of resources. Sustainable development is the development that meets the needs of the present without compromising the ability of future generations to meet their own needs. The concepts of needs and the idea of limitations are the two important concepts in it. The major objective of sustainable development is creating a better world for this generation and future generations of all living things on the Earth [1]. Currently Green concrete construction and sustainable development techniques are attaining worldwide acceptance and will prevail the future of the construction industry. This paper delves with the sustainability aspects of pervious concrete as a material in pavements.

One of the most noticeable changes in the natural environment by human is the addition of impervious area in places that were previously permeable surfaces. Impermeability of conventional concrete pavement of water and air has a highly sensitive negative impact on environment. In urban and urbanizing areas impervious surfaces have a major role in the decline of watershed integrity and production of runoff. Impervious surface generally causes to various impacts on stream systems. Higher peak stream flows which cause bank erosion, increased sediment transport, and channel incision are some of the major issues generates by the impervious surfaces. One of the other major problems is reduction of infiltration of rain water to the ground which reduces groundwater recharge and lowers stream base flows. Runoff from impervious areas like parking lots contains high amount of pollutants and increase pollutant loads to streams. Impervious surface can't capture storm water and treat it. These effects lead to hot island effects, reducing the amount of groundwater recharge, flooding, degradation of quality of water etc. [2]. Here comes the importance of Permeable Pavements and new types of permeable pavement materials like pervious concrete, used in parking areas, walk ways, light traffic roads, and shoulders.

PERVIOUS CONCRETE

The concrete which percolates water and air through its intentionally incorporated continuous voids is known as pervious concrete. Pervious concrete is also known as porous concrete, no-fine concrete, gap graded concrete, a macro-porous concrete etc [3]. By definition, pervious concrete is a mixture of gravel or granite stone, cement, water, little to no sand (fine aggregate) with or without admixtures [4]. Some of the advantages of pervious concrete are quick filtration of rainwater into ground cause to ground water recharge, air and water permeability keep the soil underneath pavement wet and alive, absorbs the noise of vehicles creates quiet and comfortable transportation environment, reduction in splash, slippery surface and no glisten at night in rainy days improves the comfort and safety of drivers and continues voids which cumulate heat and adjust the temperature and humidity of the Earth's surface and reduce heat island effect in urban areas [5].

MATERIALS

Coarse aggregate, binding materials, water and admixtures are the materials generally using in pervious concrete. The major component is course aggregate. Single size aggregates are using in pervious concrete, usually 9.5 or 19 mm (3/8 or 3/4 in.), with an optimum cementitious material which will effectively provide adequate strength without compromising the porosity. The gradation, size, and type of course aggregate effects the properties of pervious concrete. Portland cement is commonly used as the cementitious material in pervious concrete [5]. In present scenario narrow grading of aggregates are considered as an important criterion for selection of aggregates. Generally using gradations of coarse aggregate are 19.0 to 4.75 mm, 9.5 to 2.36 mm and 9.5 to 1.18 mm. Use of Single sized aggregates up to 25 mm are also acceptable. Use of fine aggregates is limited in pervious concrete mixes. Addition of small amount of fine aggregate may be providing more compressive strength but less permeability [7]. Use of Reused and Recycled waste materials in pervious concrete enhances its environmental friendliness. Several admixtures like retarders, hydration stabilizing admixtures, water reducing admixtures and air entraining admixtures. Adequate amount of water is a crucial factor in pervious concrete for cement hydration. Water quality control is very important due to the sensitivity of pervious concrete [8].

MIX PROPORTION OF PERVIOUS CONCRETE

Pervious concrete mix typically contains 270 to 415 kg/m^3 of binder material, 1190 to 1480 kg/m^3 of coarse aggregate. Water to cement ratio ranged from 0.27 to 0.4 and with admixtures it is possible in the range of 0.27 to 0.30. Optimum aggregate/cementitious material ratio by mass is 4:1 to 4.5:1. Amount of aggregate is directly proportional to permeability properties of pervious concrete and inversely proportional to strength [7].

ENGINEERING PROPERTIES

Fresh Properties

Comparing with the conventional concrete plastic pervious concrete is stiffer. For assessing quality control, it is mainly considering the unit weight or bulk density of pervious concrete. Unit weight of pervious concrete mixtures is approximately 70% of conventional concrete mixtures. Maximum working time between mixing and placing is one hour and with the use of retarders and hydration stabilizers it can be extended maximum up to one and half hour. Workability can be checked by assessing mouldability of pervious concrete by forming a ball of concrete with the hand [7].

Hardened Properties

Presence of voids makes pervious concrete a lightweight concrete. In-place density is in the range of 1600 kg/m^3 to 2000 kg/m^3 and 15 to 30% is the typical range of porosity. A 125 mm thick, with 20% voids pervious concrete pavement will be able to store 25 mm of a sustained rainstorm in its voids [7,10]. As per the Laboratories studies the 28 day compressive strength obtained to pervious concrete is in the range of 5.6 to 21MPa, with a range of void ratio 14 to 31% [6, 9]. Typical compressive strength value of pervious concrete is 17 MPa and it is suitable in a wide range of 3.5 MPa to 28 MPa. But Conventional concrete compression tests are less effective in pervious concrete because it is not possible to replicate the same compaction in the field [7]. The relationship between permeability and porosity is exponential and porosity is a typical indicator of the permeability. For a 10 MPa concrete Neithalath et al reported a permeability of 15 mm/s. in studies suggest that permeability coefficient varies from 0.25 to 6.1 mm/s [9]. General range of Flexural strength in pervious concretes is between about 1 MPa to 3.8 MPa. The present applications of pervious concrete do not require the flexural strength value for design. Drying shrinkage values of pervious concrete is in the order of 200 x10^{-6} has been reported, which is lesser than conventional concrete mixtures [7]. In the field Freeze-thaw resistance of pervious concrete is depends upon the saturation level of the voids when it freezes. Researches show that entrained air in the paste dramatically improves freeze-thaw protection for pervious concrete [10]. As far as both pervious concrete and conventional concrete concern, aggressive chemicals in soils or water, such as acids and sulphates attack in similar mechanisms. But the open structure of pervious concrete provides more contact surface and chance of attack increases as well. Rougher surface texture and open structure increase the chance of occurring of surface raveling and abrasion of aggregate particles in pervious concrete [7].

SUSTAINABLE CONCEPTS

Concept of sustainable pavements leads towards the controlling environmental stressors occurring due to conventional pavement systems. The term stressors indicates traffic and parking lot contaminants, heat due to insulation on the pavement, flow variations arising from the imperviousness of paved areas etc. The uses of pervious concretes are considered as one of the best management practices in reducing storm-water runoff by the Environmental Protection Agency (EPA) of the United States. Pervious concrete is a macro-porous concrete material which gearing towards sustainable construction and gains rapid attention in the arena of best management practices. In the sustainable point of view reduction of ill effects causing by storm-water runoff, using the ability to infiltrate water through the composite material is the primary advantage offered by pervious concretes. Reduction of tire pavement interaction noise, control of the amounts of pollutants entering the groundwater, and reduction of urban heat island effects are some other advantages of this green material. These advantages provide environmental friendly sustainable construction material badge to pervious concrete and can be attributed to its connected porosity and larger pore sizes [11]. Use of pervious concrete in permeable pavements increase the effectiveness of these qualities and provides more sustainable exposure. For a sustainable stormwater management system design pervious concrete will be an inevitable construction material. An underlying stone reservoir is associated to the pervious concrete pavements for the temporary storage of water which percolate through composite [12].

Water percolating ability of pervious concrete through its composite is the predominant property which provides this material ‘environmental friendly’ label. Hydraulic performance of the pervious concrete pavements can be accessed from surface infiltration ability. The typical water flow rates through pervious concrete are 0.2 cm/s to 0.54 cm/s, reach up to 1.2 cm/s in the laboratory tests [7]. Mix design, materials used, and the method of placement will affect the infiltration rates. In a study in cold weather climate pervious concrete provided the water permeability greater than or equal to 140 in./hour (0.1 cm/sec) [9]. Due to the entrapment of external materials like fine soil particles and organic matter voids of the pervious concrete pavements may gradually get clogged. Clogging causes to the reduction in infiltration capacity. Infiltration capacity of clogged pervious concrete pavements can be restored by the application of different rejuvenation methods [14]. Due to the open structure of pervious concrete, high porosity and interconnected voids results to increase in air circulation. The transfer of both water and air to the root zone helps to reduce development impacts on trees [8]. The light color of pervious concrete pavements absorbs less heat from solar radiation than darker conventional pavements. Relatively open pore structure of pervious concrete stores less heat and overall help to lower heat island effects in urban areas. Trees planted in parking lots and city sidewalks offer shade and produce a cooling effect in the area, further reducing heat island effects [7]. High hydraulic conductivity can substantially reduce the volume of runoff, provide ground water recharge, and minimize flooding. If the conditions are favorable like the subsurface soil is permeable to handle the water flow through the pervious concrete pavement structure then it functions like a storm water retention basin and lead to effective land use.

The pervious concrete permeable pavements are mimicking natural soil in its pollutant removal property. While stormwater from a parking lot is percolated through the pervious concrete to underlying soil, water quality can substantially improve. Captured first flush infiltrates into underneath soil structure and is allowed to treat naturally by soil chemistry and biology [13]. The pervious concrete exhibited potential for mitigating adverse impacts on the natural environment in terms of reducing total nutrient loads and pathogens from runoff water. It can reduce the total phosphorus and nitrogen load by approximately 50% or more and is effective at solid/liquid separation. Immobilization of nutrients such as Ammonium, Nitrate, and soluble Phosphorus could be possible because of microbial growth within the pervious concrete matrix and explain the low concentrations of these nutrients [15,16]. The removal efficiency of typical stormwater concentrations of dissolved zinc and copper through a layer of pervious concrete appears to be very high [17]. The water quality analysis investigated in a Pervious Concrete Infiltration Basin showed that the pollutant reduction to the surface waters was greater than 90% from inlet to outlet [18]. The large specific surface area with smaller size of aggregate and a higher void content provide pervious concrete superior ability to remove the total Nitrogen and total Phosphorous from runoff. The ability of water purification of Porous concrete using industrial byproducts is satisfactory [19]. pervious concrete pavement, when coated with Titanium dioxide and widely implemented in urban roads and highway shoulders, may result in improved air quality and thus a multi-phase cleaner transportation environment for future generations. Among the different pollutants nitrogen oxide (NO) typically reacted most effectively followed by Trimethylbenzene (TMB) and toluene in photocatalytic reduction [20].

Pervious concrete shows a good acoustic absorbing or permeating capacity due to the presence of large voids. As a result of refraction and interference, noise energy that propagates in interconnected voids is dissipated through conversion to heat [21]. The open structure results a difference in arrival time between direct and reflected sound waves, causes the noise level to have a lower intensity. Study shows that enhanced porous concrete has a quality of reducing the noise greater than 1000Hz frequency [22]. In terms of acoustic engineering, porous concrete can be considered as a rigid frame porous medium. Porous concrete is applied for sound barriers or pavements to absorb traffic (tire) noise and reduce sound wave reflection [12]. Pervious concrete appears to be a promising means to slip-resistant walking surface in areas of high pedestrian traffic. Shoe-to-pavement contact pressure for pervious concrete was found to be more than twice that for traditional concrete pavement. The dry pervious concrete pavement also had coefficients of friction two to three times greater than the traditional concrete. In comparison to traditional concrete, participants used a smaller proportion of available friction when walking on icy pervious concrete, suggesting a larger margin of safety and reduced slip likelihood. The additional contact pressure, coefficient of friction, and reduced potential for ponding water and surface freezing indicate pervious concrete may indeed be a more slip-resistant walking surface in winter conditions [23,24]. Pervious pavements are named as a BMP for stormwater pollution prevention by EPA. Use of Pervious concrete in building site design can aid in the process of qualifying For LEED green building rating system credits developed by the United States green building council (USGBC). LEED provides a framework for evaluating building performance and meeting Sustainability goals through credit categories. Sustainable Sites Credit 6.1, Sustainable Site Credit 7.1, Materials and Resources Credit 4, and Materials and Resources Credit 5 etc are the credits which can aid by pervious concrete. The intent of these credits are to limit disruption and pollution of natural water flows by Managing stormwater runoff, increasing on-site infiltration and eliminating contaminants, to reduce heat islands to minimize impact on microclimate and human and wildlife habitat and to increase the demand for building products that have Incorporated recycled content and locally available material reducing the impacts resulting from the extraction of new material [7].

CONCLUSION

Adequacy in sustainable pavement construction as a green product provides pervious concrete worldwide popularity. Pervious concrete plays an inevitable role in reducing pollutants from infiltrating stormwater runoff and provides green facilities for collecting, storing, treating and reusing stormwater. It can assist in ground water recharge and controlling flooding. With little to no runoff from the pavement surfaces stormwater retention areas may be reduced or eliminated. It is very effective, environmentally friendly in specific applications in pavements and acts as a minimizing system for heat island effect. Pervious concrete is being a new sustainable tool for landscapers and architects who wish to use greenery in pavement applications like parking lots monument premises etc. Pervious concrete with higher strength and applicability in wide range of application where higher strength required provides a new arena for future researches.

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Cite this Article
Hariram N.P. Chauhan M.S. Pervious Concrete-A Tool for Sustainable Pavement Technology: A Review. *Recent Trends in Civil Engineering & Technology*. 2015; 5(2): 12–17p.