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Effects of rice husk ash and fiber on mechanical properties of pervious concrete pavement

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HIGHLIGHTS

- Physical and mechanical properties were tested.
- Rice husk ash (RHA) and fibers were used to make pervious concrete (PC).
- These RHA could be used as pozzolan to produce PC with acceptable properties.
- The contribution of RHA and fiber to the mechanical properties was significant.
- Reduction of permeability was occurred in containing RHA and fiber concrete.

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ABSTRACT

The use of pervious concrete pavement is significantly increasing due to reduction of road runoff and absorption of noise. However, this type of pavement cannot be used for heavy traffic due to a high amount of voids and consequently low strength of pervious concrete. In this paper, rice husk ash (RHA) was used in order to strengthen pozzolanic cement paste and the effect of 0%, 2%, 4%, 6%, 8%, 10% and 12% weight percentages as a cement replacement in concrete mixtures on the mechanical properties was studied. Moreover, 0.2% V_f of glass (where V_f is the proportion of fiber volume to total volume of concrete), 0.5% V_f of steel and 0.3% V_f of polyphenylene sulfide (PPS) fibers were used to improve the mechanical properties of the pervious concrete. Also, several water to cement (w/c) ratios were made and then, physical and mechanical properties of hardened concrete including porosity, permeability, compressive strength, tensile strength and flexural strength were investigated. The results indicated a significant increase in compressive, tensile and flexural strengths. Also, in all of w/c ratios, a similar trend was observed in the compressive, tensile and flexural strengths of concrete containing RHA and fibers but the optimum percentage of RHA was different so that, it increases rapidly to the optimization point but gradually decreases after this point. The w/c ratio of 0.33 significantly increased the mechanical properties of the pervious concrete and reduces the amounts of voids and its permeability.

1. Introduction

Pervious concrete consists of cement, water and coarse aggregates (with low or without fine aggregates). Regarding the open structure of pervious concrete, air and water can penetrate into the subsoil through voids existing within the concrete. Due to connectivity of pervious concrete voids, flow pipes are generated, which work as a filter and absorb pollutants (e.g. oil or other pollutions on the ground) [1]. Pervious concrete is usually used in north of Iran because of heavy rainfalls in these regions and also its environmental benefits such as controlling runoff, restoring groundwater supplies and finally reduction of underground water pollution. Pervious concrete has acoustic properties due to its high porosity that can reduce noise pollution [2,3]. Although pervious concrete was available since the middle of 19th century, its first application in many countries specially USA and Japan was about 1980. Pervious concrete pavement is better than asphalt or ordinary concrete pavement environmentally [3]. High penetration velocity of water into pervious concrete has led into using this kind of pavement in other cases such as hydraulic structures, tennis courts, greenhouses and as a base course of heavy traffic pavements [4]. However, because of lower durability and strength of pervious concrete, compared to ordinary ones, its application is only in regions with low traffic congestion such as parking lots,

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road shoulders, streets and local roads [5,6]. Void content of pervious concrete is usually 15–25%, and it is compressive strength is about 2.8–28 MPa [4,7]. Since fine aggregates content is low or sometimes there are no fine aggregates in pervious concrete, cement paste covers coarse aggregates and preserves integrity of voids [8]. On the other hand, compressive, tensile and flexural strengths of pervious concrete is less than ordinary ones due to its high porosity and lack of fine aggregates [9]. So, the serviceability life of this concrete is less than its design life [1,10]. Several studies have been carried out on mechanical properties of pervious concrete by Sonebi and Bassuoni [11], Shu et al. [12], Chen et al. [13], Lian et al. [14] and Agar-Ozbek et al. [15].

The use of various fibers in concrete and making fibrous concrete (FRC) is an effective step in preventing the expansion of micro-cracks and cracks and compensating tensile strength weakness of concrete [16]. Important characteristics of fibrous concrete are energy absorption, flexibility and impact resistance that considerably reduce the risk of concrete failure, especially in areas under repeated loading. In general, the fibers in the pervious concrete significantly increase permeability while slightly increasing air in pervious concrete and improve its tensile strength [5,17,18].

Contact area, the interfacial zone between cement paste and aggregates or fiber, plays an important role in permeability, durability and strength of concrete and is a function of the thickness of the contact area, type of fiber, type of cement, type of pozzolan, *w*/*c* ratio and concrete age. Also, the micro-structure of the cement paste in the contact area differs from that within the cement paste and has more porosity and micro-cracks. In this experimental investigation, rice husk ash (RHA) as artificial pozzolan, was used to strengthen the contact area. Recycling the components of waste materials saves energy in cement production and preserves natural resources and environment. One of pozzolanic materials applicable in the constituent components of agricultural waste is rice husk that contains relatively large amounts of silica. In addition, the use of materials with pozzolanic reactions can often significantly improve the properties of concrete [19–21]. Due to the large number of rice paddies in the north of Iran and other areas of this country, a large amount of rice husk is produce annually. At present, these husks are of no or limited used. In addition getting rid of them will have some serious environmental issues as they are burned and a lot of smoke and pollutants are emitted. However, it should be noted that husk is a precious agricultural product and a raw industrial substance of various uses.

RHA, as a partial replacement of cement, increase compressive strength of normal concrete and its optimal value is between 10% and 30% [22]. Different studies have suggested optimal values for RHA. Andres et al. [23] reported 10% of RHA as optimal for achieving maximum compressive strength. In some studies, including a study by Ganesan et al. [24] 15% replacement leads to higher compressive strength in comparison with 10%. However, these differences depend greatly on how it is burnt which, has a direct impact on pozzolanic properties. Therefore, for a comprehensive case, the optimum range of 10–15% replacement is a better suggestion than precisely 10% replacement. It is necessary to be noted the rice husk obtained from different areas has different effects even with the same replacement percentages. For example, Gemma [25] used the same amount of RHA from two different regions and provided a good comparison between the obtained compressive strength.

In this paper, the effect of fiber type, including PPS, steel and glass fibers with different percentages of RHA (0%, 2%, 4%, 6%, 8%, 10% and 12%) on the physical and mechanical properties of pervious concrete is investigated. In addition, three water to cement (*w*/*c*) ratios of 0.27, 0.33 and 0.4 are evaluated. This study is an attempt to establish a balance between permeability and strength of pervious concrete. The compressive strength, tensile strength, flexural strength, porosity and permeability of pervious concrete are examined. The results of this study show that compressive, tensile and flexural strengths increase for up to 8–10% higher RHA replacement (as an optimized value) and then reduce for higher amounts of RHA. Also, substituting the RHA for cement is economically justifiable and also helps protect the environment. Moreover, PPS fibers have caused better improvement physical and mechanical properties of pervious concrete.

2. Experimental design

2.1. Materials

2.1.1. Aggregate

Coarse aggregate size used in this study was from 2.36 to 19 mm which is ranked #67 in the standard ASTM C33 [26]. The sand was selected from sieved No 4.75 mm equivalent value (SE = 80%). Fine and coarse aggregate curves of the used materials, according to ASTM C33, are shown in Fig. 1.

2.1.2. Cement

The cement used was of Portland type II. The chemical and physical composition is given in Table 1.

2.1.3. Rice husk ash (RHA)

Firstly, rice husk was burned for 2 h in the furnace outdoors. Black products from the furnace represent a high percentage of carbon content that reduces its pozzolanic properties. Then the ash is burned and decarbonized in a special furnace. Consequently, the ash is let to cool in the ambient temperature. This method leads to an increase in specific surface area and pozzolanic properties of RHA [27]. Chemical and physical properties of RHA can be seen in Table 2.

Comparing Tables 1 and 2, we can conclude that the amount of silica and calcium oxide, are completely different from each other in cement and RHA so that the amount of cement silica and RHA are 21.9% and 86.02%, respectively and the Calcium oxide of the cement and RHA are 63.33% and 1.12%, respectively. As it can be seen from the total chemical properties of rice husk, the total amount of silica and Al_2O_3 and Fe_2O_3 is 86.5%, which are much more than the amount (min 70%) specified in ASTM-C618 standard [28]. Thus, RHA is known as a pozzolanic

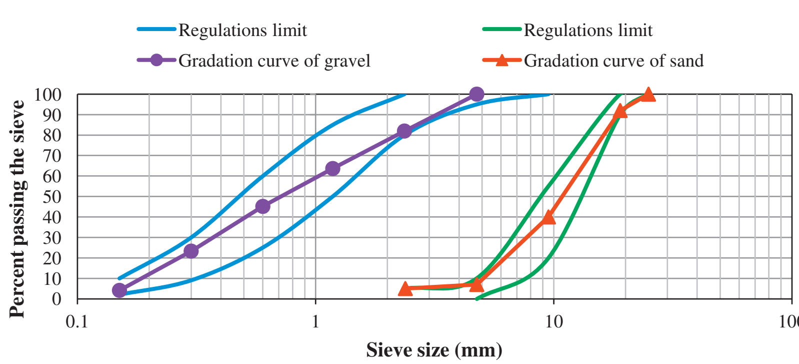

Fig. 1. Gradation curve of fine and coarse aggregates with ASTM C33 standard limits.