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Mechanical properties of roller compacted concrete containing rice husk ash with original and recycled asphalt pavement material

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ABSTRACT

This study focused on the effects of rice husk ash (RHA) on the mechanical properties of roller compacted concrete (RCC) designed with original and reclaimed asphalt pavement (RAP) materials. The RCC mixes were produced by partial substitution of cement with RHA at varying amounts of 3% and 5%. Four aggregate combinations including the mix with original aggregate, coarse RAP + fine original aggregate, coarse original aggregate + fine RAP and total RAP were considered. The main experimental design consisted of the compressive strength and three points bending tests. Bending test was used to measure the modulus of rupture, material's energy absorbency and analyse the fatigue response of RCC mixes. All tests were performed after 7, 28 and 120 days curing except the fatigue test that performed on 120 days specimens. Adding RHA resulted in higher optimum moisture content (OMC) and lower maximum dry density. Furthermore, adding RAP with different dimensions reduced the OMC and maximum dry density. The material's flexibility improved upon replacing 3% cement by RHA. However, the energy absorbency reduced by increasing the RHA content to 5%. The fatigue life of RCC mixes containing RAP material was lower than the conventional one. Furthermore, replacing the coarse aggregate by RAP led to higher fatigue life than the fine aggregate. There was a strong relationship ($R^2 > 0.90$) between the energy absorbency and fatigue response of RCC mixes. At higher stress ratios of 0.72, the mix with higher energy absorbency behaved better under repeated loadings. Besides, a reverse relationship was found between the fatigue life and material porosity. Adding 3% RHA reduced the porosity especially after 120 days curing and improved the fatigue resistance. However, the addition of RHA to 5% resulted in higher porosities and lower fatigue lives.

1. Introduction

The construction and maintenance of roads pavement should be long-lasting due to their major impact on the economy of countries. Regarding the environmental perspective pavement engineering has selected novel techniques that could result in a change that is friendlier to the environment. Some of these environmental friendly techniques include the use of recycled waste materials, pavement recycling and warm mix techniques that could reduce the pollutant gases emissions. In this regard the use of recycled materials in Portland cement concrete (PCC) pavements has become more and more popular in recent years. Roller compacted concrete (RCC) is a type of concrete which developed from standard PCC coupled with experience gained by using compacted mixtures of soil and gravel materials stabilized with Portland cement.

RCC is a zero-slump concrete which composed of dense-graded aggregate, sand, Portland cement and water which is usually placed with an asphalt paver and compacted with conventional vibratory roller compactors. Based on economical analysis the initial construction costs of RCC pavements are about 30% lower than the conventional asphalt pavements and about 10–20% lower than that of the conventional PCC. However, the hardened RCC pavement behaves like a conventional PCC [1–3].

According to the literature, RCC was firstly used in a timber manufacture plant site in Vancouver during the initials of 1970. The performance of RCC in this site which was under heavy loading traffic and severe abrasive effects was reported to be successful. Since then, RCC pavements have been extensively used in the industrial pavement areas in Canada [3].

In Europe, RCC was initially used in low traffic roads of Spain. Also since 1984 many parking lots and heavy duty military camps were paved by RCC in Texas State of America [3]. After the oil crisis

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during the 1970 decade, due to higher construction costs many conventional asphalt pavements were widely replaced by RCC pavements [3]. In comparison to flexible pavement a reduced construction costs of 30% has been reported in the literature [3].

The main parameters affecting the properties of PCC such as water to cement ratio (w/c) and density are also considered as the major criteria in designing RCCs. However the compaction properties of RCCs have been recognized as the key parameters in achieving the proper load bearing capacity [3–6]. Following the idea of the maximum density, most of RCC design instructions have recommended to compact this layer at optimum moisture content [3,4].

RCC could be used as the final surface of pavement especially in heavy duty low speed pavements such as terminals, and parking areas. However at higher traffic speeds usually a hot mix asphalt overlay is constructed to promote the skid resistance of pavement [1]. Because of lower water to cement ratio, RCC has lower bleeding potential than the traditional PCC pavements. Therefore the problem of the constitution of weak layer over the pavement surface is not the case in RCC, except for inordinate compacted layers. As a result, the higher surface quality results in lower permeability and higher durability of RCC pavements [1,3].

In recent years due to high construction costs and many environmental aspects, various recycled materials were used in PCC and RCC mixtures [7–9]. Recycled or waste materials have been utilized to replace the coarse and fine aggregates or used as cementitious additives. For example crushed PCC, recycled asphalt pavement (RAP) and crushed waste glasses are some of the recycled waste materials that have been used as coarse or fine aggregates in concrete pavements. Moreover, different natural and artificial pozzolans have been utilized as cementitious material especially for Portland cement substitution in PCC and RCC pavements [10–13].

During a research study crushed concrete slabs were used as aggregate materials in RCC pavement [12]. Based on the obtained results the technical properties of RCC containing crushed concrete slabs were comparable to conventional RCC with original high quality aggregates. However, the compressive strength of RCC with original aggregate was higher than that of designed with recycled concretes [12].

In a separate study, steel furnace slag was used as aggregate material in RCC mixture [14]. It was specified that replacing 25% of natural aggregate by steel slag will even improve the strength properties of mixture. In contrast, any further increase had adverse effects on the mechanical properties of RCC [14].

During a laboratory research study the effect of RAP materials was investigated as aggregate replacement in PCC mixture. Laboratory fabricated RAP materials were used in coarse and fine aggregate fractions. Results showed a systematic reduction in both compressive and indirect tensile strengths for the RCC mix made with RAP material. In addition it was shown that the RAP containing concrete had a much higher toughness than the conventional PCC [7].

A similar study was conducted at the university of Florida, in which RAP materials were added to PCC mixture [10]. RAP materials with different percentages of 0%, 20%, 40%, 70% and 100% were added to mixture. Results of laboratory testing indicated that compressive strength, modulus of elasticity, flexural strength and indirect tensile strength decreased by increasing the percentage of the RAP materials. However, the reduction in flexural strength was lower than that of the compressive and indirect tensile strengths. Furthermore, it was found that the addition of RAP material increased the coefficient of thermal expansion and drying shrinkage of PCC mixture [10]. By comparing the stress–strain curves of various studied mixes it was realized that adding the RAP content will increase the material's flexibility and the failure strain of PCC mix [10].

The mechanical properties of rubberized PCC were also reported in the literature. Similar to RAP, rubber reduced the strength and increased the flexibility and energy absorbency of PCC mix [15,16]. However, it was reported that compared to rubber, RAP had better chance of replacing aggregate in concrete mix especially at higher percentage of 10% by total mass of mix [7].

There are several reports that addressed the effects of fly ash as a substitute material for Portland cement and sand in PCC and RCC mixtures [17–19]. During a laboratory study circulating fluidized bed combustion (CFBC) ash was used to replace fine aggregates of RCC. This material is a waste or by-product of petroleum coke combustion power stations and has a high content of CaO and SO_3. Test results showed that CFBC ash can increase the water absorption and effectively reduce the initial surface absorption. Meanwhile, CFBC ash had a positive effect on compressive strength, splitting tensile strength and sulphate attack resistance of hardened RCC [20].

In a similar research study the strength properties of high-volume fly ash (HVFA) RCC and superplasticised workable concrete cured at moist and dry curing conditions were evaluated. Concrete mixtures made with 0%, 50% and 70% replacement of ordinary Portland cement (OPC) with two different low-lime class F fly ashes were prepared. The study showed that producing high strength concrete was possible with high volume fly ash content. HVFA concrete was found to be more vulnerable to dry curing conditions than was the OPC concrete. Finally, it was concluded that HVFA concrete was an adequate material for both structural and pavement applications [2].

During a laboratory study the strength properties of a high volume fly ash RCC was investigated analysing the rate of strength changes at various curing times. It was concluded that at early ages of curing the strength of HVFA was poor, while the fly ash effect was low or negative. Following its curing age, the strength of RCC increased rapidly; meanwhile, the fly ash effect gradually improved and was more beneficial to raising the flexural strength. Furthermore, it was found that at long curing ages its effect on high volume fly ash RCC becomes more remarkable by increasing the fly ash proportion [21].

In a similar study the influence of fly ash on the fatigue performance of RCC mix was investigated. It was found that if added at the rate of 15–30% of the cement content, fly ash improves the pore structure and increases the fatigue life of RCC mix [22]. Apart from the fly ash content and dimension, knowledge about the Portland cement and fly ash hydration mechanisms is of high importance in the practical usage of fly ash in cement mixtures. The quantity of CaO in the fly ash can determine the course of hydration and influence the strength of cement paste [23].

Rice husk ash (RHA) is a powder that affords from combustion of rice husk. This ash is a potential source of amorphous reactive silica which has a variety of applications in materials science. Most of the ash is used in the production of Portland cement. When burnt completely, the ash can have a Blaine No. of as much as 3600 cm^2/gr compared to the Blaine No. of cement between 2800 and 3000 cm^2/gr, meaning it is finer than cement. In recent years the potential use of RHA has been investigated in various pavement applications. For example it has been used as active filler in hot mix asphalt and as cement complement in conventional and special PCC mixtures [6,24,25].

The main objective of this research is to investigate the effects of RHA on the mechanical properties of RCC mixture. In this regard different mix designs were considered including RCC mixture containing original and RAP materials.

Using RAP material in RCC has several advantages. Due to bitumen coating, RAP particles have lower porosity and water absorption than the natural aggregates. Therefore, higher moisture will be available which could react with cementitious materials. Hence, the use of RAP material will help to achieve higher hydra-