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Probabilistic and experimental investigating the effect of pozzolan and Lumachelle fine aggregates on roller compacted concrete properties

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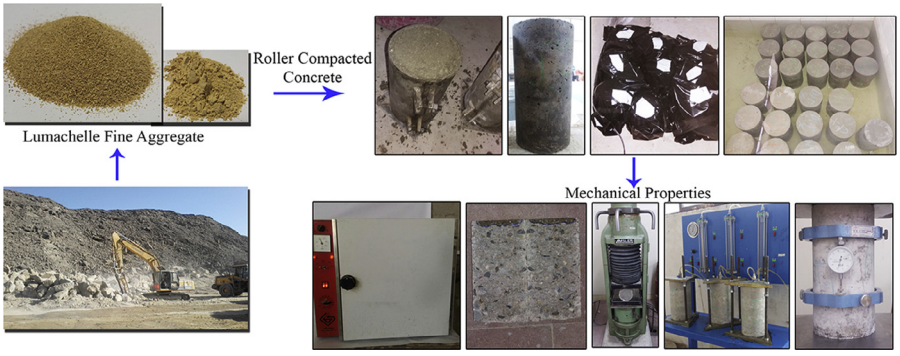
HIGHLIGHTS

- In coastal areas, Lumachelle aggregates are more than standard aggregates.
- Investigation on using Lumachelle aggregates when fine aggregates are not available.
- Different ratios of Lumachelle fine aggregates and pozzolan were used in RCC.
- Lumachelle fine aggregates can use in RCC by controlling the conditions.
- 20 percent of pozzolan provided appropriate quality for mixtures.

GRAPHICAL ABSTRACT



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ABSTRACT

Lumachelle stones, which are produced by marine sediments widely available in most coastal areas, can be considered as one of the aggregates replacements in roller compacted concrete (RCC). This study aims to evaluate the applicability of Lumachelle as fine aggregates in RCC that contains pozzolan. Three series of mixtures A, B, and C were designed based on the "dimension reduction prediction method" (DRPM). Mixes contained different water/cement ratios (W/C), varied quantities of pozzolan, and different amounts of Lumachelle fine aggregates as a replacement for the standard fine aggregate. Compressive strength, water absorption, under-pressure water penetration depth, and elasticity modulus tests were done on the specimens. Probabilistic performance evaluation and sensitivity analysis were also carried out based on the Monte Carlo simulation, the score function approach, and the DRPM. Experimental results have revealed that if optimum moisture content is calculated and used, specimens with different percentages of Lumachelle fine aggregates will have strengths close to those prepared with standard aggregates. It can be concluded, therefore, that Lumachelle fine aggregates can be used in the RCC through appropriate control of the W/C-Pozzolan ratio; Pozzolan reduces water penetration in mixes effectively causing the enhancement of concrete durability. The probabilistic evaluation results also show that the structure will have an appropriate degree of safety if an optimum moisture content is used and the construction process is controlled. Reliability sensitivity result confirms that among different random variables considered in the analysis, Lumachelle fine aggregates had the least effects on the failure of this type of concrete.

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1. Introduction

Roller compacted concrete pavements (RCC) have better durability and resistance than asphalt pavements, and they perform well against oil elements such as gasoline, diesel, and grease [1]. RCC is an almost dry mixture without any slump and compacted by vibratory rollers. More than 70–80% of RCC is made of aggregates and the main difference between RCC and ordinary concrete is more fine aggregates that fill the voids in the mixture [2]. According to the ever-increasing improvements in the global construction industry, the sources of standard aggregation have decreased and the cost of standard aggregate preparation is increasing. Therefore, researchers are after a substitute that can meet all the desirable durability/strength requirements of concrete [3]. In addition, since large-scale natural resource consumptions cause environmental problems, it is necessary to utilize local, accessible materials (even if they do not meet certain gradation/-physical requirements) to reduce costs, energy consumption, and CO_2 emission [4].

Many researchers have evaluated the effect of applying pozzolans, such as fly ash, rice husk ash, and silica fume, as substitutes for cement and aggregates. They have also studied the application of rubber particles and recyclable materials as aggregates in the properties of RCC [5–11].

Krishna Rao et al. have studied the abrasion resistance of RCC containing manufactured sand and ground granulated blast furnace slag (GGBS). Their studies revealed that the abrasion strength increased with age for all the specimens, but manufactured sand plus GGBS showed better results compared to natural sand [1].

They also performed another study on the strength of RCC having manufactured sand and fly ash and showed that an increase in fly ash reduced the compressive strength of all the mixes, but the reduction was less for a mix of 50% natural sand and 50% manufactured sand; they concluded that it was due to the pozzolanic reaction of the fly ash which lessens gradually in the course of time [12].

Saloua used compacted desert sand as a substitute for gravel and showed that it resulted in less contraction compared to ordinary sand due to less water content; its use in pavement construction was confirmed by researchers [13].

Li et al. investigated the effect of manufactured sand on the strength and abrasion resistance of concrete pavements. The investigation showed that according to roughness of manufactured materials and coarseness of the grains, the performance of concrete made of manufactured aggregate against abrasion and flexural strength is better than the concrete made of river aggregates [4].

Courard et al. used recycled materials in RCC with different cement values and showed that as regards the solid compaction, it behaved similar to concrete with standard materials, but the latter showed higher compressive strength compared to the former [14].

Madhkhan et al. showed that Pozzolan reduced the 28-day strength of the mixes, but it was regained after 90 days. They also showed that using fibers increased the compressive, tensile, and flexural strength of the samples [15].

Nili and Zaheri substituted silica fume, natural pozzolan, and fly ash as replacement of cement, and showed the maximum compressive strength was achieved by using of silica fume and fly ash, and pozzolan had the least compressive strength [16].

In their research, Mardani et al. investigated the freeze-thaw resistance and the durability characteristics of RCC with high volumes of fly ash. The studies showed that because of the cold joints between layers, the depth of water penetration under pressure is high [17].

Chi's and Huang's experiments about the effects of circulating fluidized bed combustion (CFBC) ash on the characteristics of RCC showed that CFBC ash increases compressive strength, tensile, and resistance against sulfate attack. According to the investigations, the replacement of 5% CFBC with fine aggregates had the optimum effect on the characteristics of RCC [18].

The investigations of Hesami et al. on the effect of rice husk ash and different fibers on the mechanical characteristics of the concrete pavement showed that the highest amount of compressive, flexural, and tensile strength was achieved in the W/C ratio of 0.33. Also, strength properties increased gradually until optimum moisture percentage was achieved and then began to reduce [19].

Vahedifard et al. added silica fume and pumice to RCC as a substitute for cement. The results showed that silica fume increases compressive strength and durability against the freeze-thaw cycle. However, the workability of mixtures decreased. Also, pumice decreased compressive strength and durability against the freeze-thaw cycle, but the workability of mixture efficacy increased remarkably [11].

Studies of Hesami et al. showed that the replacement of cement with coal waste powder (CWP), coal waste ash (CWA), and limestone powder (LS) in RCC needs more W/C for getting the same strength. The mixtures containing 5–10% CWA and 5% CWP had better resistance characteristics compared to the mixtures made of cement [20].

Studies of Karimpour on the effects of the time interval between mixing and compaction in RCCs having GGBS (that have Pozzolanic effects) showed that with GGBS, this interval not only affects the strength positively, but it also causes the highest compressive strength in a relatively long time after mixing [21].

In this research, Lumachelle fine aggregates (known also as coquina and shell bed) and pozzolan were used in different proportions as a substitute for standard aggregates and cement. In area where access to standard materials is relatively difficult, transportation costs are high, and Lumachelle fine aggregates are easily accessible, especially in coastal areas, using of Lumachell can decrease environmental and economic problems of RCC. Lumachelle are abundantly found in many coastal regions around the world (Fig. 1). Indicated points in this figure have been achieved from the research works during 2000–2017.

In this study 15 mixes including different percentage of aggregates were designed based on axial Design of Experiment (DoE) and tested to identify the effect of using Lumachelle and pozzolan.

The main objectives of this experimental research work were:

1. Investigating the effect of the uncertainty about the ratio of water to cement materials (W/C) in RCC characteristics.
2. Investigating the possibility of using Lumachelle fine aggregates as a substitute for standard fine aggregates in RCC.
3. Investigating the effect of using pozzolan as a substitute for cement, on mechanical properties of RCC.
4. Reliability evaluation of the RCC and approximating its failure probability based on the considered failure modes.

The reliability methods, used in this research presented first, then used materials and test results are presented and discussed in next sections.

2. Reliability evaluation

Since control over aggregates' properties and concrete behavior is difficult, concrete structures face uncertainties regarding materials, construction problems, environmental conditions, and curing. Uncertainties in structures are studied by the structural reliability