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The effect of coarse to fine aggregate ratio on the fresh and hardened properties of roller-compacted concrete pavement

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HIGHLIGHTS

- There is an optimum coarse to fine aggregate ratio for RCCP.
- Increasing cement from 9% to 12% has significant effect on the properties of RCCP.
- Coarse to fine aggregate ratio influences the porosity of RCCP.
- Relationship between tensile strengths and compressive strength were determined.

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ABSTRACT

Roller-compacted concrete pavement (RCCP) is an economic and durable rigid pavement. Although about half century has passed since the first RCCP was implemented, information about this type of concrete is still limited. RCCP as a zero-slump concrete, has lower cement content than conventional vibrated concrete. Therefore, the quality of the aggregates has a significant impact on the properties of concrete. For this reason, the quantity of coarse and fine aggregates in RCCP should be optimized. This study investigates the effect of coarse to fine aggregate (C/F) ratio on the fresh and hardened properties of two RCCPs with cement contents of 9% (204 kg/m^3) and 12% (268 kg/m^3). Compressive strength, splitting tensile strength, flexural tensile strength, Vebe time and porosity tests were carried out. The test results demonstrate that increasing the C/F ratio from 0.6 to 1.8 increased the Vebe time threefold, while increasing the cement content from 9% to 12% decreased the Vebe time by 12%. In addition, increasing the C/F ratio from 0.6 to 1.2 significantly decreased the porosity of RCCP, to about 60% for RCCP with 9% cement and 38% for RCCP with 12% cement. Generally, the most suitable C/F ratio for RCCP appeared to be from 1.2 to 1.4. Thus, to attain a workable, high-strength and durable RCCP, a mix with 12% cement and 1.2C/F ratio is recommended.

1. Introduction

Although roller-compacted concrete pavement (RCCP) contains the same ingredients as conventional concrete (cementitious materials, aggregates and water), the mixture proportions are different. RCCP is a type of rigid pavement with low water demand and low cement dosage, which requires no finishing, dowels, tie rods, or steel reinforcement [1,2]. The American Concrete Institute (ACI) defined RCCP as "concrete compacted by roller compaction that, in its unhardened state, will support a roller while being compacted" [2,3]. RCCP differs from conventional concrete principally in the required consistency, which directly affects the mix proportion requirements [4]. The load carrying capacity of RCCP is dependent on the compaction process that creates friction between the confined particles or interlocking aggregates.

Designing RCCP mixtures is based on two principal concepts: consistency based on ACI 325.10R [5] and maximum density based on ACI 211.3R [6]. In addition, Khayat and Libre [4] developed a hybrid consistency-compaction concept. The consistency approach focuses on the workability of RCCP in fresh state. According to this method, specific mixture parameters should be provided, such as the water-to-cement ratio, and the cementitious material and

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aggregate dosages. Subsequently, one parameter is adjusted by Vebe testing to attain the required consistency. In addition, each ingredient can be amended to achieve suitable fresh and hardened RCCP properties.

In contrast, the soil compaction approach concentrates on the relationship between the optimum moisture content and maximum dry density of RCCP. In this method, aggregate grading is very important, and sieve analyses should be conducted for coarse and fine aggregates. The soil compaction approach is often proposed for small to medium-size projects [7]. The hybrid consistency-compaction concept takes workability and maximum density into account. Khayat and Libre [4] reported a combination of river sand, and crushed stone of 12.5 mm and 25.4 mm, in proportions of 48%, 17%, and 35% respectively, as the optimum combination for RCCP. Fig. 1 shows the percentage retained on each sieve. Khayat and Libre also reported that 20–40 s Vebe time is suitable for a good RCCP.

RCCP needs more aggregate skeleton for consolidation under compaction compared with conventional concrete. Aggregate gradation affects RCCP compactability as well as the minimum number of vibrating passes required for full consolidation [2,8]. RCCP requires aggregate grading similar to that of asphalt concrete mixtures because the same method of placement and compaction is employed [9]. The aggregate content in RCCP is higher than in conventional concrete. It is typically 75–85% of the total volume of RCCP compared to 60–75% in conventional concrete [10,11]. Suitable aggregate grading and the correct selection of coarse-to-fine aggregate (C/F) ratio are key factors for obtaining a good RCCP mixture in terms of workability, compactability, minimizing voids, reducing segregation, as well as surface finish. In addition, correct aggregate selection affects the water requirement and need for cementitious materials for an RCCP with acceptable mechanical properties. Usually, coarse aggregates are limited to a nominal maximum size of aggregate (NMSA) of 19 mm to prevent segregation and achieve a tight surface. In addition, the NMSA should be smaller to improve riding quality [4]. A fine aggregate volume smaller than 75 μm (fine aggregate passing through sieve #200) in an RCCP mixture has a significant effect on this type of concrete, in both fresh and hardened states [2,4]. However, RCCP mixtures reportedly often require a higher proportion of fine to coarse aggregate compared to conventional concrete, which can result in a more homogenous mixture and reduce the risk of segregation [2,4]. An RCCP with low cement content needs careful aggregate

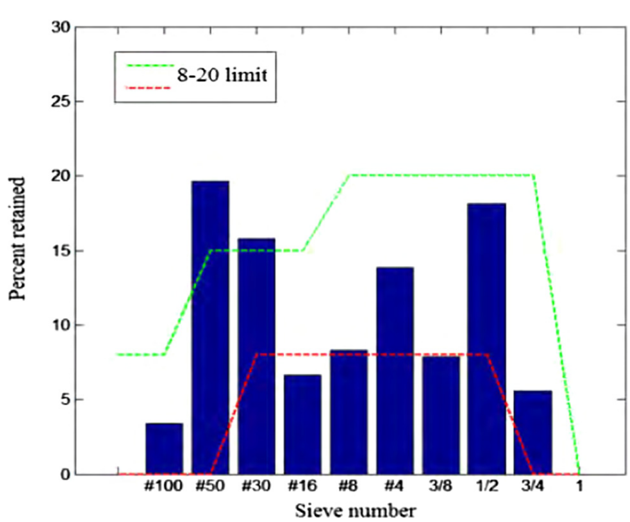

Fig. 1. Percent retained on each sieve for selected aggregate combination [4].

structure selection to ensure adequate structural performance of the pavement [12].

As concrete technology has recently been developing, researchers realize that aggregates can greatly influence important characteristics of concrete, such as strength, volume stability, ultimate tensile strength and durability [13]. Due to the significant role of aggregate in RCCP mixtures, some researchers have studied the effect of aggregate properties on the fresh and hardened properties of RCCP. Different mixture proportions used in several projects in North America indicate that the maximum grain size of coarse aggregate varied between 12.5 and 25.4 mm and fine aggregate of <75 μm was in the 0–7% range [2,4,12]. However, it should be noted that there is no specific recommendation for selecting the C/F ratio for an RCCP mixture. According to previous studies as well as RCCP mixture implementation in road construction, the C/F ratio in RCCP mixtures varies between 0.65 and 1.6 [2,4,12,11]. ACI and the Portland Cement Association (PCA) propose C/F ratios of 0.55–1.5 [2,14,15]. However, this range is very wide and is not applicable for selecting RCCP mix proportions.

Thus, the aim of this study is to determine appropriate C/F ranges for RCCP mixtures with different cement contents. The experimental part of the study focuses on hardened properties, such as compressive strength, splitting tensile strength, flexural strength and porosity by testing at early ages of 1 and 7 days as well as 28 days.

2. Experimental program

Experiments were done in three phases. First of all, the materials and equipment were prepared and initial tests were conducted to identify the material properties. In the second step, a suitable aggregate grade and the mix design were defined by testing several initial mix designs. Finally, the main specimens were prepared with different C/F ratios and then tested at specific ages.

2.1. Materials used

2.1.1. Cement

The binder employed was Ordinary Portland Cement (OPC) conforming to MS522 part-1:2003 with compressive strengths of 36 and 48 MPa at 7 and 28 days, respectively. The OPC had a specific gravity and specific surface area of 3.14 and 3510 cm^2/g, respectively.

2.1.2. Aggregates

Local mining sand with a fineness modulus of 2.8, saturated-surface-dry (SSD) specific gravity of 2.55 and 24 h water absorption of 1.5% was used in all mixtures. The crushed coarse aggregate used in this investigation had a maximum nominal size of 19 mm, SSD specific gravity of 2.62 and 24 h water absorption of 0.67%. The grading curves of coarse and fine aggregates were within ASTM C33 standard limits, as shown in Fig. 2. Moreover, the grading curves of aggregates for RCCP mixtures with different coarse to fine aggregate ratios and with 9% and 12% cement contents were compared with the 0.45 power maximum density curve in Figs. 3 and 4, respectively. In these figures, “A” represents for 9% cement content and “B” denotes for 12% cement content RCCP mixtures.

2.2. Mix proportions and mixing procedure

In this study, two groups of RCCP were used, containing 9% and 12% Portland cement by mass of total dry solids (204 and 268 kg/m^3), respectively. Each group consisted of C/F ratios between 0.6 and 1.8 (at 0.2 intervals). The mix proportions of all concretes are given in Table 1.