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Modelling of the adhesion between reclaimed asphalt pavement aggregates and hydrated cement paste

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HIGHLIGHTS

- Incorporation of RAP reduces the compressive strength of concrete.
- SEM images proved the poor adhesion between RAP and the cementitious matrix.
- Concrete produced with 60% RAP could be used in the construction of rigid pavements.
- RAP/cementitious matrix adhesion quality could be quantified using the LCPC model.
- LCPC model could be used to predict the compressive strength of RAP concretes.

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ABSTRACT

Scanning electron microscope images on concrete incorporating 100% RAP material showed the presence of voids between cement paste and RAP aggregates indicating the poor adhesion between these two constituents. Therefore, the LCPC French model, was used with compressive strength data of different RAP concrete mixes to determine the adhesion and threshold parameters of the model. It was found that the adhesion parameter decreases as the RAP content increases while the threshold parameter remained constant for all RAP contents. The model with its described procedure could be used to proportion RAP concretes for any targeted compressive strength.

Introduction

One of the most used rehabilitation technique of hot-mix asphalt (HMA) surfaced pavements is the placement of an HMA overlay after cold milling, with specially designed equipment, the upper surface to a specific depth. The milled surface has good macrostructure that improves adhesion with the new HMA overlay which plays the role of restoring the pavement surface to a specified profile with no ruts, humps, and other imperfections. In addition, the milled material commonly known as reclaimed asphalt pavement (RAP), has been successfully used in developed countries for the formulation of new HMA [1] and portland cement concrete mixes [2], which saves on the consumption of new aggregates from natural deposits. However in many developed countries, RAP is still considered as waste or occasionally used as fill material during the construction of rural roads. For instance, in Tunisia, the average annual produced amount of RAP is estimated at 200,000 tons, but no significant usage of this material was adopted by pavement agencies. This led the authors to investigate the possibility of using this material in the construction of rigid pavements given the availability of portland cement in the country.

Several research teams have studied portland cement concrete with RAP as aggregates. They looked in particular into the effect of RAP on the concrete compressive strength and its indirect tensile strength through laboratory experimental testing [2–13]. All the reported results showed that these properties decrease with an increase in the percentage of incorporated RAP. Some researchers examined experimentally the RAP effects on concrete elastic modulus with the same finding that is a decrease in this property

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with an increase in RAP content [4–6,9,12]. All of these cited studies are based on experimental testing and most of the authors attributed the decrease in mechanical properties to the low adhesion between the cement paste and RAP. In fact, the bond strength of the interfacial zone between coarse aggregate and cement paste is governed by the former surface characteristics (mainly its roughness) and on chemical bonding depending on the minerals found in the aggregates. RAP has an asphalt film that reduces their roughness and inherent any chemical bonding that might have occurred between the minerals contained in the aggregates and the cement paste. In addition, the asphalt film is considered as a hydrophobic material chemically incompatible with hydrophilic cement paste [14–16]. This reduction in adhesion is not only a characteristic of RAP, but also with many other waste materials that are added to concrete such as tire rubber and plastic fibres [17–18]. Therefore, several researchers have proposed adequate solutions to improve the quality of adhesion between incorporated waste materials and cement paste [19–21]. The processing of these waste materials would improve concrete performance, but the cost of concrete production is increased as well. For this financial reason, no processing (fracture of particles or taking out of binder) was performed on the RAP studied in this research as it was used in its milled state. One theoretical investigation, used to explain the reduction of concrete performance with increased RAP content is that of Mathias et al. published in 2009 [22]. In that study the researchers extended the use of the "Laboratoire Central des Ponts et Chaussées" (LCPC) French model, originally developed by de Larrard to characterize concrete mixtures [23], to those containing RAP. However, two different assumptions were postulated – RAP was treated as a homogenous aggregate in the first assumption, while the asphalt phase was assumed to be finely dispersed within the cement paste in the second one. The authors found that with the second assumption the predicted model values fit better the experimental results.

In the research work described in this paper, scanning electron microscope (SEM) was used to have images of a concrete mix made by 100% RAP as aggregate and an equivalent mix with no RAP. These images made it possible to see the structure of RAP concrete in order to use the best assumption during its theoretical modelling. Different concrete mixes with different percentages of RAP were formulated and tested for their compressive strength at different ages. The LCPC model was then used and the RAP adhesion and threshold parameters were determined.

1. Observations using SEM

SEM observations were performed on two concrete mixtures — one made with 100% new quarried aggregates and one made with 100% RAP. The mixes are labelled as F0 and F100, respectively and their design is presented in the next section of the paper. The observed specimens were sampled from the centre of fabricated prismatic beams ($7 \times 7 \times 28\ cm^3$). The specimens are approximately 2 cm in length so that they can be introduced into the SEM chamber. Prior to testing, the specimens were prepared by polishing their surface using several silicon carbide (SiC) abrasive papers; the polishing was repeated by increasing the papers' grit sizes until a planar, smooth, and shiny surface was achieved. An example of a prepared specimen and the SEM testing machine are shown in Fig. 1.

As shown by Fig. 2, SEM observations with a 40-times magnification factor showed a continuous structure for concrete F0. No visible voids are observed at this magnification level on the concrete surface; whether on the hydrated cement paste (hcp) or on the transition zone between the hcp and coarse aggregates. Even when the magnification level is increased to 600-times, the observed surface still does not show any discontinuities or voids. At this magnification level, the aggregate and the hcp seem also

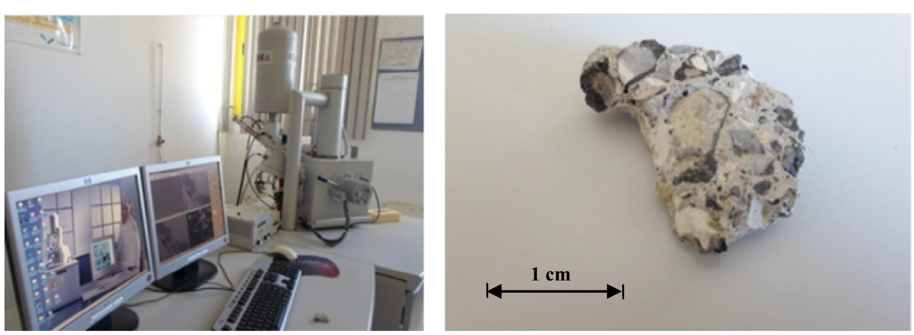

Fig. 1. SEM Testing equipment (left) and specimen (right).

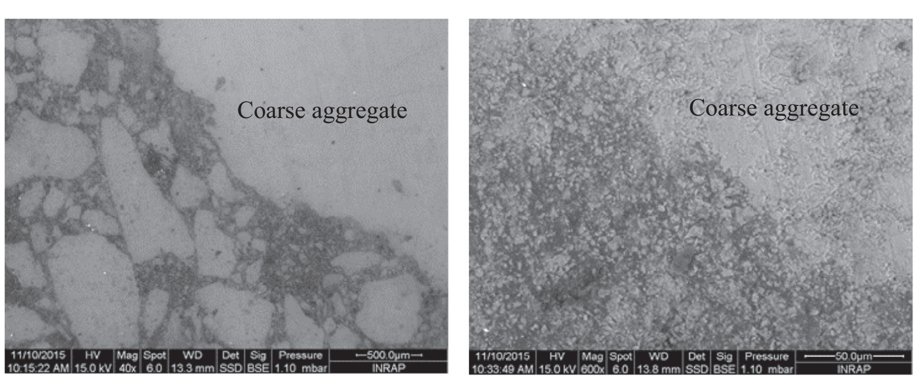

Fig. 2. SEM imaged of F0 specimen (a) 40 × magnification (b) 600 × magnification.