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Development of a semi-flexible heavy duty pavement surfacing incorporating recycled and waste aggregates – Preliminary study

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HIGHLIGHTS

- The cold mixtures are used in grouted macadam replacing the traditional mixtures.
- The RAP and altered granites use is an alternative to natural aggregates.
- The cementitious grouts are incorporated with milled glass and waste mud.
- The cold mixture with altered granite and S30MG presents the best characteristics.

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ABSTRACT

This paper analyses the possibility of using altered aggregates and Reclaimed Asphalt Pavement (RAP) in cold mix asphalt used to produce grouted macadam pavements in comparison with the conventional hot mix porous asphalt skeleton. It also investigates the cementitious grouts performance when incorporated with milled glass and Panasqueira Waste Mud and geopolymerics grouts. This paper aims mainly at studying the introduction of mineral waste materials in grouted macadam pavements. The results indicate that the cold mixture 8/12.5 with altered granite and cementitious grout with 30% milled glass presents the best mechanical performance.

1. Introduction

The recycling of asphalt pavements is nowadays used worldwide as a major road and airport pavements rehabilitation technique due to the increasing cost of asphalt, the scarcity of quality aggregates, the pressing need to protect the environment and the increasing disposal costs of old asphalt pavements [1–5].

Road rehabilitation and rehabilitation operations can be classified into two main classes dependent on pavement material types: flexible (asphaltic, bituminous composites) and rigid (cementitious, concrete, pozzolanic composites). In this investigation, an innovative semi-flexible hybrid composite pavement type, where the surface course comprises a semi-flexible material, has been developed with the objective of combining some of the best qualities from both flexible and rigid pavements surfaces. This type of composite road surfaces are commonly named grouted macadams. In grouted macadams, the flexible, jointless, water proofing properties that characterize asphalt are accompanied by a high static bearing capacity, rutting and wear resistance, as well as resistance to oil and fuel spillage that are characteristic to conventional concrete surfaces [6–9]. The mechanical properties of grouted macadams lend themselves ideally to scenarios where a combination of slow and heavy traffic is prevalent, including industrial areas, airports, ports, bus terminals, cargo centres, etc.

The first development of the semi-flexible pavements was carried out in the 50's, in France, as a surface course protection against the oils and fuels spillage [10]. Between 1988 and 2000, 165,000 m^2 of grouted macadams were constructed in Copenhagen Airport [11], which is a practical example of the application of these pavements. Since then, several studies have been conducted to investigate the performance characteristics of this pavement surfaces type [12–15].

The process of constructing a grouted macadam layer is composed of two stages. In the first stage, a hot mix porous asphalt with high voids content (25–35%) is laid with a traditional asphalt

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paver and lightly compacted. In the second stage, the porous asphalt layer is impregnated with a highly flowable self-compacting cementitious grout [16,17].

This paper includes results of a laboratory investigation into the properties of a grouted macadams range impregnated with a number of grouts that incorporate innovative formulations capable of replacing conventional materials of natural origin. In particular, milled glass and a selected waste mud were utilized in formulating highly workable cementitious grouts. Marsh Cone flow time measurements were supplemented with additional rheometric measurements in order to more fully characterize the grouts (e.g. yield stress and relative plastic viscosity).

Additionally in this investigation, conventional aggregates normally used in porous asphalt production were replaced with Reclaimed Asphalt Pavement (RAP) or altered aggregate, and were incorporated into a cold mix porous asphalt skeleton. The advantages of using a cold mix asphalt include ease of mixing and handling; eliminating the requirement for large sized production plants and allowing rapid installation even in remote areas; energy savings; reducing emissions; and health and safety benefits [9]. The performance of these cold mix asphalt skeletons were compared with a conventional hot mix asphalt produced with natural aggregates. The resultant grouted macadam composites characterization was carried out by using the following tests: indirect tensile stiffness modulus, Marshall stability, compressive strength and resistance to permanent deformation.

2. Materials

2.1. Asphalt skeleton

2.1.1. Aggregates

The aggregates used in this study were natural granites (5/15), altered granites (8/12.5) and RAP. All mixtures incorporated limestone filler. In Table 1 the selected mechanical and volumetric properties, including bulk density, water absorption and percent crushed aggregates are presented. The RAP bitumen content, as well as its bulk density, are indicated in Table 1.

2.1.2. Binders

In the case of the conventional hot mixture asphalt, a 100/150 pen grade bitumen was used. For the cold mixture asphalt, a Polymer Modified Emulsion (PME) manufactured by CEPSA, with the commercial product name of Styemul was used. The binders characterization was based on the penetration test, with measured penetration values of 128 dmm for the 100/150 pen grade bitumen, and 220 dmm for the PME residue. As far as the softening point test is concerned, the 100/150 pen grade bitumen had a softening point temperature of 42.2 °C whilst the PME had a softening point of 43.0 °C.

2.1.3. Open-graded asphalt design

Knowledge gained from the literature proved essential for producing the standard porous asphalt mixture. Anderton [12] and Oliveira [14] were the main references used for the mixture design and production processes.

The conventional mixture was produced with 97% of 5/15 aggregates and 3% of limestone filler. The 5/15 aggregate was further sieved into two separate sizes 8/12.5 and 10/12.5 and these were also used to manufacture porous asphalt skeletons to appreciate the gradation effect on porous asphalt. The optimum bitumen content was determined at 4.2%.

The porous asphalt slabs (300 × 300 × 50 mm) were produced with a vibrating compactor to determine the porosity of the mixtures. In the hot mix porous asphalts, mixing was conducted at 170 °C, whilst the compaction temperature was fixed at 130 °C. Following impregnation of the porous asphalt slabs with the various grout formulations, the cured slabs were subsequently cored to produce cylindrical grouted macadam specimens of 104.4 mm in diameter. Measurements of the void contents of the various compacted asphalt slabs revealed that all the skeletons produced had porosity values in the range from 29% to 32%, which was deemed within the acceptable limits for this investigation.

2.2. Grouts formulations

In this investigation, 12 cementitious grout formulations in addition to 4 geopolymeric grout formulations were developed and tested. The cementitious grout designs utilized specific combinations of water/cement ratios, superplasticiser type and content, and cement replacement type and content. On the other hand, the geopolymeric grouts were manufactured using a waste mud activated with various concentrations of alkali solution.

An overview of the various cementitious and geopolymeric compositions are presented in Tables 4 and 5, respectively. The following sections present additional details of the various grout components.

2.2.1. Superplasticisers

Two types of superplasticisers were used in formulating the cementitious grouts, each having a different activation principle, based on the studies of Anderton [12] and Setyawan [15]. Anderton utilized a styrene–butadiene based admixture to improve particle adhesion and ultimately grout flexural strength. Setyawan, on the other hand, used a water/cement ratio lower than Anderton's mixtures, with the aid of third generation superplasticisers (Polycarboxylate-based admixture), in order to achieve low viscosities. Superplasticisers play an important action in the production of more durable grouts with improved rheological characteristics [18]. Taking into account the various water/cement ratios proposed by Anderton and Setyawan, Table 2 presents the water/cement ratios adopted in this investigation to produce a Weaker grout (W) and a Stronger grout (S).

2.2.2. Cement replacement materials

The milled Glass (MG) used in this investigation was processed from recycled bottles. The glass used was soda-lime type, composed essentially of silica, as well of sodium and calcium oxides. A tubular ball mill device coated with neoprene was used for the milling process. For an average final particle size of 125 μm the milling time was determined by using a ratio mass/time of

Table 1
Aggregates properties.

	5/15 granite	5/15 altered granite	RAP
Bulk density (kg/m^3)	2620	2610	2410
Water absorption (%)	0.87	1.12	–
Crushed aggregates (%)	23.15	26.01	–
Bitumen content (%)	–	–	5.60

Table 2
Weaker and stronger grouts design (* % of cement mass).

	Anderton (2000)	Weaker grout	Setyawan (2003)	Stronger grout
Water/cement	0.65–0.75	0.6	0.28	0.28
Styrene–butadiene admixture (%)*	2.5–3.5	3	–	–
Polycarboxylate-based admixture (%)*	–	–	1	1