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A new mix design method for steel fibre-reinforced, roller compacted and polymer modified bonded concrete overlays

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HIGHLIGHTS

- A new mix design method for polymer modified, bonded concrete overlays is proposed.
- Main requirements for the mix were: roller compactability and paver placeability.
- Optimal water content was a key element for the roller-compacted, concrete overlay.
- The modified light compaction method (M-L) guarantees high strength and good bond.

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ABSTRACT

For roller compacted concrete used in pavements, optimal water content is one of main concerns for mix design. However the mix design method aiming at achieving both high bond strength and roller *compactability* is not available so far. The modified Proctor compaction method and modified Vebe method were investigated and found to be inappropriate to the type of mixes in terms of durability. In this paper a method for determining optimal water content is proposed for steel fibre-reinforced, roller compacted and polymer modified bonded concrete overlays. Two types of mixes suitable for asphalt paver placement and roller compaction were developed: They were the SBR and the SBR–PVA hybrid polymer modified cement concrete mixes with the optimal water contents determined by the proposed method. Both mixes achieved good bond with the old concrete substrate.

1. Introduction

A vast number of worn concrete pavements used in airfields, highways and urban roads, are rehabilitated every year around the world. The utilisation of bonded concrete overlays (BCOs) can be more sustainable, environmentally friendly and cost effective than the complete removal and replacement of the old concrete pavement. Conventional concrete overlays bonded on old concrete pavements are increasingly gaining acceptance in United States [1–3]. However compared to roller compacted concrete (RCC) pavements, the construction process is slow and unfavourable due to long traffic disruptions.

BCO can offer significant savings, since maximum use is made of the existing structural concrete pavement. However, the overlay has to provide adequate toughness, crack control, high flexural and bond strength and good resistance to fatigue. The constituents and proportion of RCC for pavements have been extensively investigated. The RCC mix designs are mainly focusing on determining the optimal water content. The methods currently available for determining optimal water content are the modified Proctor (M-P) compaction method [5,6] and the modified Vebe (M-VB) method [7,8], although they relate exclusively to plain RCC (without steel fibres).

Recently, Kagaya et al. [9] carried out laboratory studies with steel fibre reinforced RCC, using the M-VB method. Neocleous et al. [10] employed the M-P method to develop mixes containing recycled steel fibre reinforced in RCC pavements. However, the abovementioned mix design methods were for pavements resting on a sub-base or a sub-grade but not applicable to bonded concrete overlays. In the present study a good bond between the overlay and the existing concrete pavement is the key to its success. Therefore, it is necessary to develop a new mix design method for steel fibre reinforced, roller compacted bonded overlays. The method proposed in this paper introduces an innovative approach in determining the optimal water content in RCC mixes when used as pavement overlays. Two types of mixes were developed to achieve good bond with existing concrete.

2. Mix constituents, workability and design criteria

2.1. Mix constituents and their properties

Steel fibres and polymers, such as Styrene Butadiene Rubber (SBR) and Polyvinyl Alcohol (PVA), were selected to be included in the mixes to enhance the

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resistance of pavement to reflective cracking and ensure good bond with the existing concrete substrate. Hence the full name of mixes is 'steel fibre reinforced, roller-compacted, polymer modified, bonded concrete overlay'. It should be pointed out that the mix constituents of the SBR modified cement concrete used in this study were first considered by Koutselas [11] in an earlier research programme, in which the types of aggregate, glass fibre, SBR, PFA (pulverized fuel ash) and MTK (metakaolin) were extensively investigated and carefully selected.

The physical properties of materials used are presented in Table 1. The physical properties of cement, SBR, PVA, steel fibre, MTK, PFA and superplasticizer were provided by the suppliers/manufacturers, while coarse aggregate and fine aggregate were tested by the authors in accordance with the relevant British Standards.

The physical properties and chemical compositions of cement, MTK and PFA, provided by the corresponding manufacturers are listed in Tables 2–4. In this study, sand ratio is defined as sand (fine aggregate) to total aggregate (fine aggregate plus coarse aggregate) ratio by weight. The gradations of combined aggregates with sand ratio of 0.345 and 0.4 and 0.5 are presented in Table 5.

2.2. Mix workability and mix design criteria

The focal point of the present RCC mix designs is the determination of the optimal water content. In order to simulate conventional concrete overlays on old concrete pavements in the laboratory, ordinary Portland cement concrete (OPCC) composite cylinders and blocks were first studied. They were fabricated and cured in water prior to testing. Their mechanical properties in 28-day age are listed in Table 6. The OPCC mix proportion in Table 6 was similar to that used in conventional bonded concrete overlays in successful, real pavement sites [4]. Their tensile bond strength was reported equal to 1.65 MPa compared to our splitting tensile bond strength of 2.17 MPa. Thus, the OPCC-to-OPCC bond strengths obtained, were selected to be the lower strength boundary for steel fibre reinforced, roller-compacted bonded concrete overlay.

For RCC bonded overlays in construction, mixes should be dry enough to be placed by asphalt pavers and compacted by vibrating rollers. However, dry mixes may lead to poor bond with existing concrete pavements. On the other hand, good

Table 1
Materials used and properties.

Materials	Properties	Supplier/manufacturer
Cement	Cement-I, 52.5 N, specific density 3150 kg/m^3	Hanson Heidelberg Cement Group, UK
Coarse aggregate (CA)	Crushed gritstone, size 4.75–10 mm, impact value 12.9%, apparent particle density on oven dry 2790 kg/m^3, particle density on saturated surface-dried basis 2770 kg/m^3, water absorption 0.5%	Tarmac Ltd., UK
Fine aggregate (FA)	Quartz river sand, apparent particle density 2670 kg/m^3, fineness modulus 2.476, water absorption 0%	Coventry Building Supplies, UK
SBR	White liquid, solid ingredient content 46% by weight, water content 54%, specific density 1040 kg/m^3	Everbuild Building Products, UK
PVA	Polyvinyl Alcohol, GH-17S, white powder and water soluble, specific density 1250 kg/m^3	NIPPON GOHSEI, Japan
Steel fibre (SF)	Length 35 mm, hooked-end, rectangular section 0.45 mm × 0.6 mm, tensile strength 1050 MPa, aspect ratio 60	Propex Concrete Systems Corp., UK
MTK	Matakaolin, white powder, the specific density 2507 kg/m^3, loss on ignition 1%,water demand (Mars cone) 900 g/kg	AGS MINERAUX, France
PFA	Pulverized Fuel Ash, powder, specific density 2090 kg/m^3	Drax Power Station, UK
Superplasticizer	Auracast 400, liquid, dark straw, specific density 1020 kg/m^3	Fosroc Ltd., UK

Table 2
Physical properties and chemical composition of cement-I, of Hanson Heidelberg, UK.

Physical property	Chemical compound by weight (%)								
Loss on ignition	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	K_2O	Na_2O	Cl
3.30%	20.06	4.42	2.67	64.04	1.19	3.1	0.71	0.21	0.05

Table 3
Physical properties and chemical composition of PFA, of Drax Power Station, UK.

Physical properties		Basic oxide composition (average by weight (%))						
Loss on ignition	Fineness	SO_3	CaO	MgO	K_2O	Al_2O_3	Fe_2O_3	SiO_2
4.80%	25.10%	0.77	2.8	1.5	3.1	24.7	8.8	51.2

Table 4
Physical properties and chemical composition of MTK, of MINERAUX, France.

Physical characteristics			Basic Oxide Composition (average by weight (%))					
Loss on ignition	Pozzolanic index (Chapelle test)	Specific area (BET)	TiO_2	CaO + MgO	$Na_2O + K_2O$	Al_2O_3	Fe_2O_3	SiO_2
1%	1100 mg $Ca(OH)_2$/g	17 m^2/g	1.5	0.3	0.8	40	1.4	55

Table 5
Gradation of combined aggregate.

Sand ratio	Cumulative passing by weight (%)									
	14 mm	10 mm	6.3 mm	4.75 mm	2.36 mm	1.18 mm	600 μm	300 μm	150 μm	75 μm
0.345	100	95.32	45.21	37.53	30.35	28.28	23.65	3.81	0.98	0.15
0.4	100	95.72	49.82	41.95	35.19	32.78	27.42	4.41	1.14	0.18
0.5	100	96.43	58.18	51.63	43.99	40.98	34.28	5.52	1.42	0.22