Advances in Technology Innovation, vol. 8, no. 4, 2023, pp. 290-302

Utilizing Ultra-High Performance Concrete Overlay for Road Pavement Repair and Strengthening Applications

Lay Boon Tan[1], Milad Hafezolghorani[2], Azman Mohamed[1,*], Khaled Ghaedi[3], Yen Lei Voo[2]

[1]Faculty of Civil Engineering, Universiti Teknologi Malaysia, Johor, Malaysia

[2]Dura Technology Sdn. Bhd., Chemor, Perak, Malaysia

[3]Research and Development Center, PASOFAL Engineering Group, Kuala Lumpur, Malaysia

Received 10 July 2023; received in revised form 27 August 2023; accepted 04 September 2023

DOI: https://doi.org/10.46604/aiti.2023.12587

Abstract

This study aims to develop a new thixotropic ultra-high-performance concrete (UHPC) overlay for the repair and strengthening of damaged hot mix asphalt (HMA) pavements. The overlay is purposely designed to accommodate the roadway slope of up to 10% due to the presence of viscosifying agent materials. The original UHPC materials are comprised of granite aggregate, ultra-fine calcium carbonate, shrinkage-reducing admixture, viscosifying agent, and expansive agent. The study is conducted with three sets of samples provided and considers thixotropic and mitigated shrinkage properties by comparing control (non-thixotropic) overlay 1 (thixotropic), and overlay 2 (thixotropic) mixtures. Based on the obtained results, only overlay 1 corresponds to the minimum requirement for pavement rehabilitation, with 160-200 mm flowability and -545.3 μm/m free shrinkage. As a result, an average 50 mm thick overlay 1 is selected to repair a damaged HMA pavement (1800 m^2), while the field implementation procedures and drawing details are also presented in this paper.

Keywords: UHPC overlay, fiber-reinforced pavement, repair, strengthening, hot mixed asphalt

1. Introduction

The hot mix asphalt (HMA) pavements can be constructed with less budget and difficulty, hence why it is pervasively used not only in Malaysia but worldwide. However, the deterioration of existing flexible HMA pavements is a quotidian problem in the entire world. Various techniques can be employed to restore damaged HMA pavements, such as grouting to seal surface cracks, partial or full-depth patching, replacing existing pavement, and overlaying with asphalt [1-3]. While each of these techniques can increase the service life of the damaged pavement, none of them has been manifested to prevent further pavement deterioration [4].

An alternative repair method is the employment of conventional concrete overlays on top of HMA pavements. The concrete overlays on asphalt are also widely known as “white topping” in the United States of America [5]. Vandenbossche and Sachs [6] reported that the bond between asphalt and concrete is critical to ensure that the pavement behaves as a single structure, especially for very thin white topping overlays. In 2022, the European Concrete Paving Association published a “Guide for Design of Concrete Overlays” [7], and the guideline mentioned the bonded concrete overlays of asphalt (BCOA) pavements can augment the structural capacity and ameliorate surface friction and noise. The concrete thickness of conventional white topping overlay is equal to or more than 200 mm. The thin white topping overlay retains a thickness of more than 100 mm but less than 200 mm [8].

---

[*] Corresponding author. E-mail address: azmanmohamed.kl@utm.my

English language proofreader: Chih-Wei Chang

Although the normal strength concrete of white topping overlay technique results in somewhat high durability and life expectancy compared with HMA pavement, it has weaknesses such as lofty shrinkage, low tensile strength, long curing time, and requires a thick layer of concrete less cost-effective [1, 9]. Most problems with the conventional concrete overlay, such as corrosion and slow curing, are caused by the used material.

The concept of employing ultra-high-performance concrete (UHPC) as an overlay was pioneered in Switzerland and has been deployed on numerous bridges in Europe [10-12]. The UHPC is a fiber-reinforced and Portland-cement-based product with advantageous fresh and hardened properties. Moreover, the UHPC is emerging as an ideal alternative for preservation and restoration, while proffering an effective and durable solution for extending the service life of existing infrastructure, minimizing impact on the end users [13-15]. Thus far, the research on the employment of the UHPC overlay technique is limited. In comparison with normal strength concrete, UHPC material is at least 4 times stronger than it in compression and 7 times higher than it in flexural [16-17]. Therefore, it seems a thin layer (less than 100 mm) of UHPC material is sufficient to obtain extraordinary strength and a durable protective layer when compared with normal concrete material.

Furthermore, the UHPC also yields rapid curing with a minimum compression strength of 70 MPa within 24 hours [18], which enables the work to be delivered expeditiously within a short road closure period. On the other hand, UHPC material also exhibits superior ductility, durability, energy-absorption characteristics, and watertight and load resistance capacity [19].

Nowadays, the UHPC overlay application is the most popular in Europe, the United States, and Canada that only used for the rehabilitation of damaged normal concrete bridges [14]. In 2014, the UHPC accounting for 130 m^3 in total was cast on the deck slab of the Moudon viaduct for the waterproofing layer, the zones showing reduced structural resistance due to rebar corrosion in Switzerland, and strengthening the cantilever slab parts [12]. The most notable UHPC overlay deployment was in the rehabilitation of the 2.1 km Chillon Viaducts in Switzerland. In the prevision of weaker concrete strength, it was decided to strengthen the deck slab with a 40 mm thick layer of UHPC [20].

The first U.S. deployment of UHPC as a bridge deck overlay was completed on a reinforced concrete slab bridge located on Laporte Road bridge in Mud Creek in May 2016 [21]. The performance of typical UHPC as a filed-cast overlay, (e.g., industrial floors, industrial pavements, and white toppings) embodies several disadvantages, mostly related to the low water/binder ratio, such as workability, finish-ability, and autogenous shrinkage [22-23]. The total shrinkage of concrete is mainly composed of autogenous shrinkage and drying shrinkage while drying shrinkage is relatively low in UHPC. However, it exhibits substantial autogenous shrinkage due to the low water-to-cement ratio [24].

According to the French standard, NF P18-470 [25], UHPC without any heat treatment shall have a total shrinkage amplitude of around 700 microstrains. Reported values of UHPC shrinkage (free shrinkage according to ASTM C157 [26] tests) are normally more than 700 microstrains. Moreover, ASTM C157 does not capture the volume change in the first 24 hours, which can be high in UHPC [27]. In terms of rheological properties, the typical UHPC has self-consolidating (non-thixotropic) characteristics, whereas it can be formulated to emerge thixotropic behavior for overlay applications. Thixotropic UHPC is specially formulated to be situated on a slope given its higher yield stress at a fresh state compared with a self-consolidating one. A thixotropic UHPC will remain solid-like under static conditions and will flow when agitated or screed [28].

Based on the extensive review of the literature, exiguous information on field implementation of UHPC overlay on top of damaged HMA pavements is presented. In addition, the interaction between UHPC overlay and HMA pavements is yet to be comprehended. While several repair methods exist, more durable solutions to address ongoing pavement deterioration are needed, particularly in high-traffic zones. Despite the potential benefits of UHPC overlays, it seems the existing literature is limited in this specific application area. As a result, in this study, a thixotropic UHPC overlay was implemented on a damaged HMA road pavement in Malaysia, and the bonding between the UHPC and the HMA layer was investigated.

2. Thixotropic UHPC Mix Design

The components of UHPC are a dry mix (ordinary Portland cement, silica fume, silica sands), water, steel fibers, and a high-range water-reducing agent. To obtain a thixotropic UHPC with a minimum amount of autogenous shrinkage, adequate amount of granite aggregate (< 8 mm), ultra-fine calcium carbonate ($CaCO_3$), viscosifying agent (VA), shrinkage reducing admixture (SRA), and expansive agents (EA) were entailed for the mix. To attain the required performance of UHPC, powder materials, and fine aggregates are blended or proportioned to an adequate particle size distribution to maximize the density or compactness.

In this research project, a customized 100-liter UHPC ribbon mixer and a customized single-shaft UHPC mixer with a capacity of 10 cubic meters were deployed for laboratory-scale trial mixes and the casting of pilot a UHPC overlay. The specimens deployed in this experiment are prepared following the French standard for UHPC material, as it is currently the sole available standard for UHPC, NF P18-470 [26]. Control specimens, including cubes, cylinders, and prisms, are cast into plastic and steel molds. Subsequently, they are vibrated for 20 seconds to effectively compact the mixtures. The control specimens in the molds are covered with a 90% efficacy curing compound to prevent early water loss UHPC, and subsequently demolding after 24 hours. These specimens are cured under room conditions for 28-days.

Table 1 Mix design of thixotropic DURA® UHPC

Ingredient	Mass (kg/m^3)
Thixotropic UHPC dry mix	2000
$CaCO_3$, VA, SRA, and EA	100
Superplasticiser	28
High-strength steel fibers	157
Total water	165
Targeted W/B ratio	0.15
Total air voids	< 4%

Table 1 presents the mix design for the thixotropic DURA® UHPC with 2% steel fibers by volume of concrete. The steel fibers used have a minimum tensile strength of 2850 MPa. The high-range water-reducing agent used is a polycarboxylate ether (PCE)-based superplasticizer and no recycled wash water is employed in the mixing. The consistency of UHPC is determined by a flow table test as per ASTM C230M [29] during mixing and before casting. A flow value of 160-200 mm was measured as shown in Fig. 1. This UHPC can be modified to thixotropic behavior that enables the material to accommodate up to 10% super-elevation of the roadway.

(a) Before tapping (b) After tapping (170 mm) (c) 10% slope surface

Fig. 1 Flowability of thixotropic DURA® UHPC according to ASTM C230

In this study, an attempt was made to investigate three distinct UHPC mix designs to identify the most suitable UHPC formulation for overlay applications. The focus was on augmenting the properties of UHPC that are essential for overlaying deteriorated surfaces. To achieve this, various components were analyzed for their impact on UHPC overlay shrinkage.

Specifically, the effects of granite aggregate, $CaCO_3$, VA, SRA, expansive admixture EA, and polyvinyl alcohol (PVA) were explored and documented in Table 2. In this exploration, EA, SRA, PVA, and the inclusion of granite aggregate were strategically employed to mitigate the occurrence of shrinkage within the UHPC overlay.

Furthermore, the study addressed the thixotropic behavior of UHPC, which is vital for its application on sloped surfaces. To improve this behavior, $CaCO_3$ and VA were utilized, which enables the UHPC to maintain its consistency and proper casting properties even on inclined surfaces. This adaptation becomes crucial for ensuring the successful application of the UHPC overlay on a variety of real-world scenarios, such as roadways or bridges with varying angles.

The study's findings not only shed light on the impact of various additives on UHPC overlay shrinkage but also proffer insights into the deployment of these additives to tailor UHPC properties for specific applications. The detailed breakdown in Table 2 aids in understanding the composition and characteristics of each mix, which is essential for replicating or adapting these findings in practical construction scenarios. Overall, the present research study contributes to the furtherance of UHPC technology and its practical application for overlaying purposes, particularly in the context of deteriorated surfaces and sloped structures.

Table 2 Mix design ingredients for shrinkage tests

No	Mix name	Drymix (kg/m^3)	$CaCO_3$, VA, SRA, and EA (kg/m^3)	Admixture (kg/m^3)	Steel fiber (kg/m^3)	Total water (kg/m^3)	PVA (kg/m^3)	Flow ASTM C230 (mm)
1	Control	2100 (no granite)	-	28	157	165	-	210-230
2	Overlay 1	2000 (with granite)	100	28	157	165	-	160-200
3	Overlay 2	2000 (with granite)	100	28	157	165	3.25	150-170

Three different shrinkage tests were conducted as illustrated in Fig. 2. Based on the obtained results, Table 3 manifests the shrinkage test results of three UHPC mixtures. As shown in Table 3, overlay 1 has less restrained and autogenous shrinkage than the control mix. The control mix has the highest autogenous shrinkage. Although overlay 2 shows a lower amount of restrained and free shrinkages, the flowability and workability of this UHPC did not correspond to the requirements for floor screeding due to the presence of PVA and granite aggregates. The flow table test results of control, overlay 1, and overlay 2 mixtures are measured and shown in Table 2. By using PVA, the flowability reduction stands up to 20%, which exacerbates the difficulty and time consumption for the laying and screeding process of UHPC. Hence, overlay 1 was utilized for repairing and strengthening deteriorated 1800 m^2 HMA pavement in Malaysia.

(a) Free shrinkage (b) Restrained shrinkage (c) Autogenous shrinkage

Fig. 2 Conducted shrinkage tests

Table 3 Shrinkage results according to different standards

No	Mix name	Free shrinkage acc. ASTM C157	Restrained shrinkage acc. ASTM C1581	Autogenous shrinkage acc. ASTM C1698	Unit
1	Control	-502.7	-110.5	-835.5	µm/m
2	Overlay 1	-545.3	-73.0	-640.1	µm/m
3	Overlay 2	-538.0	-62.0	-691.6	µm/m

3. Field Implementation

The UHPC overlays are currently used for the rehabilitation of damaged conventional concrete bridge decks in Europe countries, China, the USA, etc. The research and development behind this concept were pioneered in Switzerland, and scarce highway bridges were coated with UHPC overlay to improve existing RC decks. Insufficient research is available regarding the application of a thin layer of UHPC on top of damaged HMA roads. Thus, the first pilot UHPC overlay project was proposed by the Public Works Department (PWD) of Malaysia to repair, monitor its condition over the service life of the roads, and augment the existing HMA pavement. An average 50 mm thick UHPC overlay was successfully implemented on damaged HMA road pavement located in Perak State with 200 m in length and 9 m in width, as shown in Fig. 3.

Fig. 3 Location of the first pilot UHPC overlay in Chemor, Perak, Malaysia

At the inception of the project, several severe surface damages of HMA were observed (cracks, rutting, and potholes), which probably occurred due to heavy vehicles, low wear, and impact resistance of the existing HMA pavement. Fig. 4 shows the deterioration of existing HMA pavement.

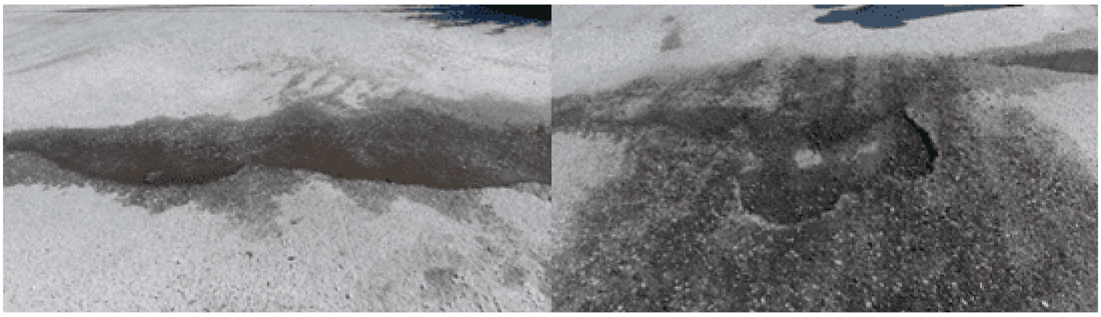


Fig. 4 Examples of existing surface damage of HMA pavement

Before the milling process, a licensed surveyor was appointed to measure the existing road profile at the original level to maintain the same road profile after overlaying as shown in Fig. 5(a). Meanwhile, Figs. 5(b) and 5(c) show marking and coring on the existing road before the commencement of field testing. A field density test (FDT) was recorded to evaluate the soil condition of existing road pavement. An average compaction and moisture content of 90% and 5.5% were recorded, respectively from 5 different locations (Figs. 5(d) and 5(e)). In addition, the same locations of FDT were employed to conduct the coring test. Therefore, an average HMA thickness of 100 mm was recorded in Fig. 5(f).

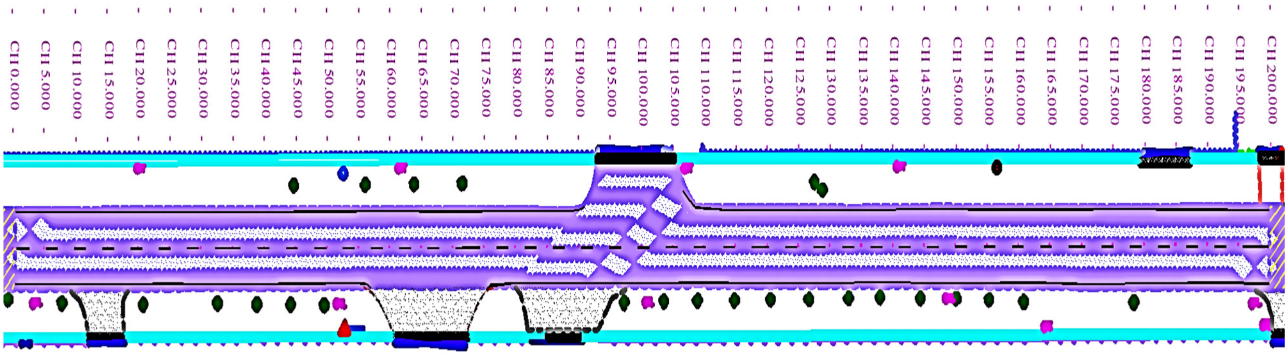
(a) Survey before milling (b) Marking

(c) Coring for field testing (d) FDT test on-site

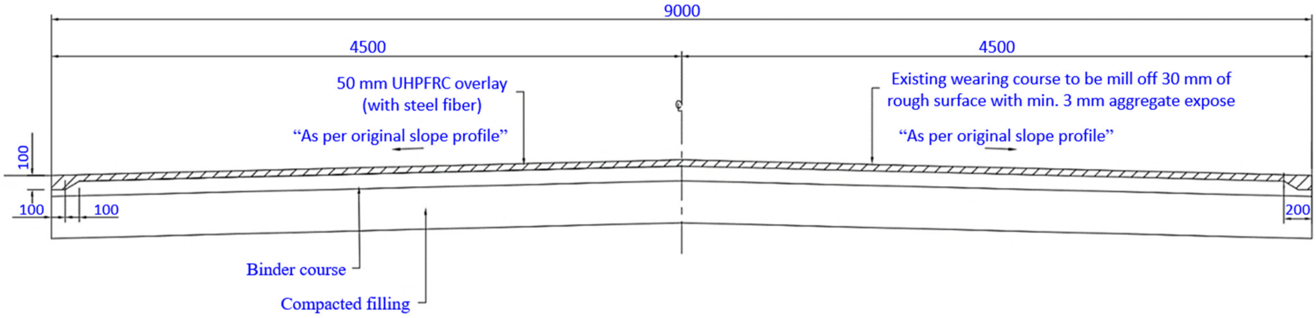
(e) Close view FDT (f) 100 mm thick existing HMA

Fig. 5 Field density test

For the pilot project, a comprehensive site plan was meticulously prepared, incorporating precise 5-meter intervals to facilitate the accurate measurement of the existing HMA levels. This detailed depiction can be observed in the visual representation presented in Fig. 6(a). Furthermore, to provide a comprehensive view of the proposed enhancements, a detailed cross-sectional illustration is presented in Fig. 6(b). This depiction showcases a typical cross-section of the planned pilot UHPC overlay, measuring substantial 50 millimeters in thickness and spanning an impressive width of 9 meters.



(a) Plan view of the existing HMA pavement



(b) Typical cross-section of construction stages

Fig. 6 Proposed thin topping UHPC overlay for 200 m by 9 m pavement

(a) Milling process (b) 40-50 mm mill-off

(c) Formwork installation (d) Rebar installation for the joints

Fig. 7 Milling, rebars, and formwork installation processes

The construction began with the 40-50 mm removal of the old asphalt layer using a Wirtgen 1900 milling machine from the existing 200 m road. To acquire a better interface bond strength between UHPC and HMA, the interface was roughed with a minimum 5 mm depth as shown in Figs. 7(a) and 7(b). Fig. 7(c) manifests the side formwork installed to control the thickness of UHPC at road shoulders. Moreover, to minimize the shrinkage at the construction joint between UHPC and HMA, 100 × 150 mm L-shape T12 rebars (300 mm c/c) were installed horizontally with 150 mm embedded depth as depicted in Fig. 7(d). Fig. 8(a) shows the milled surface of the HMA road after construction rebars and formworks installation. The water jet and blower methods were used to remove contaminants like dust, oil, grease, etc. Pre-wet process and bonding agent application before starting casting UHPC overlay are shown in Fig. 8(b).

(a) Surface cleaning (b) Applying bonding agent

Fig. 8 Cleaning and applying bonding agent on the pavement surface

The first application of UHPC overlay on a damaged HMA pavement was situated with around 100 m^3 UHPC. The HMA pavement was rehabilitated with the new thixotropic UHPC by forklift, but it was found difficult to control the screed process (Fig. 9(a)). To resolve the problem on-site, the contractor was able to use a 20-tonne mobile crane to cast and deposit in front of the screed machine which assisted in achieving a quality finish and maintaining the proper profile (Fig. 9(b)). Hence, the 200 m length ultra-thin topping UHPC layer was cast and situated using a 12 m^3 capacity shaft mixer on 3 consecutive nights from 6 pm to 3 am to prevent shrinkage cracks due to hot ambient temperature during the daytime.

(a) Forklift (b) Mobile crane

Fig. 9 UHPC transported by forklift and mobile crane

(a) Screeding and leveling (b) Curing

Fig. 10 Pilot UHPC overlay procedure

(c) Saw cutting (d) Road marking and UHPC overlay completion

Fig. 10 Pilot UHPC overlay procedure (continued)

Manual and automatic vibratory concrete screed machines were employed for situating and leveling the material as shown in Fig. 10(a), and a concrete curing compound with 90% efficiency was sprayed immediately on top of the UHPC overlay to maintain the moisture content in the UHPC mix and reduce early shrinkage cracks (Fig. 10(b)). The surface was textured using a spiked roller after the initial set time of 45 to 90 min. Once the UHPC overlay achieved a minimum compression strength of 70 MPa, the contraction joints with 5 m c/c and 10 mm depth (t/4) were sawed as shown in Fig. 10(c) and followed by road marking in Fig. 10(d).

4. Results and Discussion

In this research, three different UHPC mix designs were tested to select the best UHPC for overlay purposes. The impacts of granite aggregate, $CaCO_3$, VA, SRA, EA, and PVA were investigated on the shrinkage of the UHPC overlay (refer to Table 2). The EA, SRA, PVA, and granite aggregate were used to reduce the shrinkage. Furthermore, $CaCO_3$ and VA were utilized to improve the thixotropic behavior of UHPC that allows casting on slopes.

Table 4 summarizs the mechanical properties of the thixotropic UHPC used for the repair and strengthening of 1800 m^2 HMA pavement. Overlay pavement was cast from eight different batches of a new thixotropic UHPC. Samples were collected for all 8 batches to measure 1-day and 28-days cube compressive strength test and 28-days cylinder compressive strength test. 72 cubes with 100 mm in length and 48 cylinders with 100 mm × 200 mm in diameter in total were cast. It should be noted that the target UHPC grade used for this study is C120/135 (characteristic strength of cylinder/cube). Mean characteristic strength values (f_{cm}) for cube and cylinder specimens are determined by calculating the average of 48 test specimens. Ultimately, the characteristic value (f_{ck}) is determined by subtracting the product of the structure coefficient (SC) and the standard deviation (SD) from the f_{cm} obtained from experiments as:

$$f_{ck} = f_{cm} - \left(SC \times SD\right) \tag{1}$$

From Table 4, the 1-day mean cube strength was measured to be $f_{cm,cube,1d}$ = 87 MPa which is higher than the specified passing value, that is 70 MPa (to open the traffic road). The 28-days characteristic compressive strength for the cylinder and cube specimens was measured as $f_{ck,cyl,28d}$ = 123 MPa and $f_{ck,cube,28d}$ = 142 MPa, respectively. It is deemed to meet the minimum specified strength C120/135.

In addition to the compression strength test, flexural-tensile strength tests were conducted on the UHPC overlay mix using the test method given in Annex D French standard [25]. The objective of these tests is to convert the flexure-tensile strength test data to obtain the mean and characteristic values of the elasticity limit in tensile (i.e., $f_{ctm,el}$ or $f_{ctk,el}$) and post-cracking tensile strength (i.e., f_{ctmfm} or f_{ctfk}) of the UHPC. As mentioned in French standard [25], the design tensile characteristic values of $f_{ctm,el}$ = 8 MPa, $f_{ctk,el}$ = 7 MPa, f_{ctfm} = 9 MPa, and f_{ctfk} = 8 MPa is recommended. 36 pieces of 100 mm × 100 mm × 500 mm prism samples in total were cast in this research.

As shown in Table 4, the characteristic tensile values measured are $f_{ctk,el}$ = 7.5 MPa and f_{ctfk} = 10.2 MPa, which are higher than the required values. Furthermore, the mean tensile values measured are $f_{ctm,el}$ = 8.7 MPa, and f_{ctfm} = 12.4 MPa which are higher than the recommended values by the French standard. The mean and characteristic flexural strengths were measured as f_{cfm} = 29.9 MPa and f_{cfk} = 24.0 MPa, respectively. Ultimately, the UHPC overlay used in this research corresponded to the design material strength requirement as per the design French standard [25].

Table 4 Summary of the developed UHPC overlay material

Items	1st-day cube comp.	28th-days cube comp.	28th-days cyl comp.	Flexural-tensile strength (Annex D, NF P18-470)		Flexural strength [modulus of rupture (MOR)]
No of samples	24	48	48	18	18	18
Mean (MPa)	87	150 ($f_{cm,cube,28d}$)	134 ($f_{cm,cyl,28d}$)	8.7 ($f_{ctm,el}$)	12.4 (f_{ctfm})	29.9 (f_{cfm})
SD	-	4.9	6.7	0.9	2.4	2.9
SC	-	1.645	1.645	-	-	-
COV (%)	-	3.3	5.0	6.7	8.7	9.7
Characteristic (MPa)	-	142 ($f_{ck,cube,28d}$)	123 ($f_{ck,cyl,28d}$)	7.5 ($f_{ctk,el}$)	10.2 (f_{ctfk})	24.0 (f_{cfk})

After completing the overlay, a field study to assess the bond between the UHPC and the underlying HMA surface was conducted. The test setup consists of two samples including a cored cube and cylinder HHPC pull-off disc bonded to the prepared testing surface. A partial core is subsequently cut around the disc, and the disc is pulled off using a tensile testing machine. The pull-off force (F) is divided by the cross-sectional area of the partial core to obtain the pull-off strength (f_p), as presented in the following formulas for both the cube and cylinder discs:

$$f_p = \mathrm{F}/\pi a^2 \quad (\text{for the cubic disc}) \tag{2}$$

$$f_p = 4\mathrm{F}/\pi d^2 \quad (\text{for the cylindrical disc}) \tag{3}$$

where F is the pull-off force. a and d are the length and diameter of the pull-off disc for cube and cylinder discs, respectively. The test parameters are shown in Fig. 11.

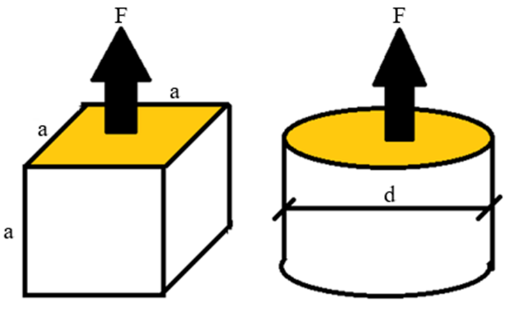


Fig. 11 Pull-off test schematic view

(a) Direct pull-off test

(b) Bond test

Fig. 12 In-situ bond tests

Fig. 12 shows in-situ direct pull-off bond test preparation and the bond testing procedure that has been conducted in this study. 10 pull-off tests in total were conducted on different locations of the UHPC overlay upon completion of the repair and strengthening process. An average 0.26 MPa bond failure between UHPC and existing HMA pavement was measured which indicated low bonding strength. The low bonding strength can be attributed to the quality of existing HMA pavement, whereas the UHPC overlay is periodically monitored. Thus far, no concerns have emerged regarding the performance of the new UHPC overlay or the bond at the interface between the UHPC and HMA layers. It is noted that the pull-off test conducted in the present study is according to ASTM C1583/C1583M-13.

5. Conclusions

The UHPC overlay is preponderantly deployed for the rehabilitation of damaged normal concrete bridge decks in numerous countries. However, exiguous information on the field implementation of the UHPC overlay on top of damaged HMA pavements is presented. The novelty of the study lies in the investigation and selection of the optimal UHPC mix design for overlay applications, focusing on enhancing properties relevant to overlaying deteriorated surfaces. Three different UHPC mix designs were evaluated to determine the most congruous with overlaying purposes. The study examined the effects of various components, including granite aggregate, $CaCO_3$, VA, SRA, EA, and PVA on the shrinkage behavior of UHPC overlays. The incorporation of EA, SRA, PVA, and granite aggregate was employed to mitigate shrinkage, while $CaCO_3$ and VA were utilized to ameliorate thixotropic behavior, facilitating casting on slopes. By comparing the mix designs and assessing parameters such as shrinkage, flowability, and mechanical properties, overlay 1 emerged as the most conducive option for repairing and strengthening a deteriorated HMA pavement. Based on the aforementioned statements, the following conclusions were drawn:

(1) The repair and strengthening of damaged road pavement were successfully implemented using UHPC overlay technology in Perak State, Malaysia for the first time.

(2) A thixotropic UHPC applicable to surfaces up to 10% slope with a minimum amount of shrinkage was developed in this study.

(3) The UHPC overlay technology is an attainable technology enabling the work to be delivered expeditiously within a short road closure period of less than 24 hours.

(4) A thin layer of 50 mm UHPC overlay was sufficient to obtain enough bond at the interface between the UHPC overlay and HMA with extraordinary strength and a durable protective layer.

(5) The research evaluated the bond strength between the UHPC overlay and the rudimentary HMA surface, noting challenges related to bonding strength but observing satisfactory ongoing performance. However, further inspection is required for the next few years to monitor the bonding strength.

(6) The UHPC overlay technique assists in achieving a significantly more sustainable road with minimum maintenance due to the excellent mechanical and durability properties of UHPC material.

(7) The present study proffers insights into optimizing UHPC formulations for effective overlay applications, contributing to the field of infrastructure rehabilitation and preservation.

In conclusion, the installation method of reinforcement bars (dowel bars) at the construction joints is a challenge to maintaining the continuity of the overlay structure. Therefore, further research is suggested to elaborate on the limitation.

Conflicts of Interest

The authors declare no conflict of interest.

References

[1] M. Pomoni, C. Plati, and A. Loizos, “How Can Sustainable Materials in Road Construction Contribute to Vehicles’ Braking?” Vehicles, vol. 2, no. 1, pp. 55-74, March 2020.

[2] L. Uzarowski and I. Bashir, “Rational Approach for Selecting the Optimum Asphalt Pavement Preventive and Rehabilitation Treatments-Two Practical Examples from Ontario,” 2007 Annual Conference and Exhibition of the Transportation Association of Canada: Transportation-An Economic Enabler (Les Transports: Un Levier Economique), article no. 01098890, October 2007.

[3] R. O. Rasmussen and D. K. Rozycki, Thin and Ultra-Thin Whitetopping: A Synthesis of Highway Practice, Washington DC: Transportation Research Board National Research Council, 2004.

[4] S. S. Adlinge and A. K. Gupta, “Pavement Deterioration and Its Causes,” International Journal of Innovative Research & Development, vol. 2, no. 4, pp. 430-450, April 2013.

[5] R. Kumar and R. Mathur, “Whitetoppings-An Engineered Economical Long-Lasting Solution for Distressed Roads,” https://cpwdeablogging.wordpress.com/2012/04/21/whitetopping-an-engineered-economical-long-lasting-solution-for-distressed-roads/, April 21, 2012.

[6] J. M. Vandenbossche and S. Sachs, “Rehabilitation Strategies for Bonded Concrete Overlays of Asphalt Pavements,” University of Pittsburgh, Technical Note, August 12, 2013.

[7] M. B. Snyder, “Guide for Design of Concrete Overlays,” Brussels: European Concrete Paving Association, 2022.

[8] G. J. Fick, J. Gross, M. B. Snyder, D. Harrington, J. Roesler, and T. Cackler, “Guide to Concrete Overlays,” Ames IA: National Concrete Pavement Technology Center, Iowa State University, 2021.

[9] S. Hou, T. Xu, and K. Huang, “Investigation into Engineering Properties and Strength Mechanism of Grouted Macadam Composite Materials,” International Journal of Pavement Engineering, vol. 17, no. 10, pp. 878-886, 2015.

[10] H. Wibowo and S. Sritharan, “Use of Ultra-High-Performance Concrete for Bridge Deck Overlays,” Bridge Engineering Center, Institute for Transportation, Iowa State University, Departmental Report, March 21, 2018.

[11] Z. B. Haber, J. F. Munoz, and B. A. Graybeal, “Field Testing of an Ultra-High Performance Concrete Overlay,” U.S. Department of Transportation, Federal Highway Administration, Technical Report FHWA-HRT-17-096, September 21, 2017.

[12] K. Wassmann and E. Brühwiler, “Strengthening of RC Slabs Using UHPFRC-Concepts and Applications,” 4th International Symposium on Ultra-High Performance Concrete and High Performance Materials, pp. 1-10, March 2016.

[13] Z. B. Haber, A. Foden, M. McDonagh, J. M. Ocel, K. Zmetra, and B. A. Graybeal, “Design and Construction of UHPC-Based Bridge Preservation and Repair Solutions,” U.S. Department of Transportation, Federal Highway Administration, Technical Report FHWA-HRT-22-065, May 05, 2022.

[14] B. A. Graybeal, “Design and Construction of Field-Cast UHPC Connections,” U.S. Department of Transportation, Federal Highway Administration, Technical Report FHWA-HRT-19-011, February 17, 2019.

[15] M. A. Helsel, J. F. Muñoz, Z. B. Haber, and I. De la Varga, “Effect of Bridge Deck Surface Preparation on the Consolidation and Bond of UHPC Overlays,” Construction and Building Materials, vol. 364, article no. 129860, January 2023.

[16] Y. L. Voo, M. Hafezplghorani, and S. J. Foster, “Application of Ultra-High-Performance- Fiber Reinforced Concrete Technology for Present and Future,” Proceedings of the 2nd International Conference on UHPC Materials and Structures, pp. 30-44, November 2018.

[17] Y. L. Voo and S. J. Foster, “Characteristics of Ultra-High Performance ‘Ductile’ Concrete and Its Impact on Sustainable Construction,” The IES Journal Part A: Civil & Structural Engineering, vol. 3, no. 3, pp. 168-187, 2010.

[18] M. Hafezolghorani and Y. L. Voo, “Design of 38m Span Post-tensioned Ultra High Performance Fiber-Reinforced Concrete (UHPFRC) Composite Bridge,” IOP Conference Series: Materials Science and Engineering, vol. 431, no. 4, article no. 042007, October 2018.

[19] S. Y. Hiew, K. B. Teoh, S. N. Raman, D. Kong, and M. Hafezolghorani, “Prediction of Ultimate Conditions and Stress–Strain Behaviour of Steel-Confined Ultra-High-Performance Concrete Using Sequential Deep Feed-Forward Neural Network Modelling Strategy,” Engineering Structures, vol. 277, article no. 115447, February 2023.

[20] M. Bastien-Masse and E. Brühwiler, “Contribution of R-UHPFRC Strengthening Layers to the Shear Resistance of RC Elements,” Structural Engineering International, vol. 26, no. 4, pp. 365-374, 2016.

[21] S. Sritharan, G. Doiron, D. Bierwagen, B. Keierleber, and A. Abu-Hawash “A UHPC Overlay for Deteriorated Bridge Decks,” 3rd International Symposium on Ultra-High Performance Fibre-Reinforced Concrete, pp. 797-806, October 2017.

[22] P. Buitelaar and R. Braam, “Heavy Reinforced Ultra Thin White Topping of High Performance Concrete for Re-strengthening and Rehabilitation of Structures and Pavements,” 8th International Symposium on Utilization of High-Strength and High-Performance Concrete, pp. 1262-1269, October 2008.

[23] W. Guo, Y. Wei, L. Ma, Y. Liu, and R. Guo, “Effect of Grouped L-Shape Rebar Connectors on the Shrinkage Behavior of UHPC Overlay Cast on Hardened NSC Substrate,” Construction and Building Materials, vol. 382, article no. 131319, June 2023.

[24] C. Androuët and J. P. Charron, “Shrinkage Mitigation of an Ultra-High Performance Concrete Submitted to Various Mixing and Curing Conditions,” Materials, vol. 14, no. 14, article no. 3982, July 2021.

[25] Concrete-Ultra-High Performance Fiber-Reinforced Concrete-Specifications, Performance, Production and Conformity, Association Francaise de Normalisation NF P 18-470, 2016.

[26] Standard Test Method for Length Change of Hardened Hydraulic-Cement Mortar and Concrete, ASTM C157/C157M-08, 2008.

[27] S. V. Shann, “Application of Ultra High Performance Concrete (UHPC) as a Thin-Bonded Overlay for Concrete Bridge Decks,” Master thesis, Department of Civil and Environmental Engineering, Michigan Technological University, United States, 2012.

[28] J. Du, P. Guo, Z. Liu, and W. Meng, “Highly Thixotropic Ultra-High-Performance Concrete (UHPC) as an Overlay,” Construction and Building Materials, vol. 366, article no. 130130, February 2023.

[29] Standard Specification for Flow Table for Use in Tests of Hydraulic Cement, ASTM C230/C230M-20, 2021.

Copyright© by the authors. Licensee TAETI, Taiwan. This article is an open-access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY-NC) license (https://creativecommons.org/licenses/by-nc/4.0/).