Volume 14, Issue 5

May 2023

American Concrete Institute
Malaysia Chapter

MYCONCRETE

THE BULLETIN OF THE AMERICAN CONCRETE INSTITUTE - MALAYSIA CHAPTER
(E-bulletin)

Highlight!

Upcoming Event

Annual Concrete Seminar

70-1, Jalan PJS 5/30,
Petaling Jaya Commercial City (PJCC), 46150 Petaling Jaya, Malaysia
Email: admin@acimalaysia.org
Tel: +60 (3) 7782 2996 | Fax: +60 (3) 7782 1196 | H/P: +60 (14) 220 7138

MyConcrete:
The Bulletin of the American Concrete Institute – Malaysia Chapter

Editor:
Ms. Serina Ho Chia Yu
Hume Cement Sdn. Bhd.

70-1, Jalan PJS 5/30, Petaling Jaya Commercial City (PJCC),
46150 Petaling Jaya,
MALAYSIA

🌎 http://www.acimalaysia.org
☎ +6014 220 7138
🖂 admin@acimalaysia.org

The opinions expressed by the contributors are of the individual authors and not necessarily those of the Editorial Board of American Concrete Institute - Malaysia Chapter. The publication may include case studies or advertisement of suppliers who have, in one way or other contributed in the development of this publication. The American Concrete Institute - Malaysia Chapter does not endorse the products included in the case studies and advertisement. It is the responsibililty of the users to select appropriate products to ensure they meet their specific requirements.

Published in Malaysia by
American Concrete Institute - Malaysia Chapter
70-1, Jalan PJS 5/30, Petaling Jaya Commercial City (PJCC),
46150 Petaling Jaya, Malaysia.

Table of Content

Thank You Sponsors!

We take this opportunity to thank our sponsors for their contribution and support for this month’s edition of MyConcrete e-Bulletin.

Premium Sponsor **JKS REPAIRS SDN BHD**

INTRODUCTION TO ACI MALAYSIA CHAPTER

American Concrete Institute - Malaysia Chapter (ACI-Malaysia) is a non-profit technical and educational society representing ACI Global in Malaysia, which is one of the world's leading authorities on concrete technology. Our members are not confined to just engineers; in fact, our invitation is extended to educators, architects, consultants, corporate, contractors, suppliers, and leading experts in concrete related field. The purpose of this Chapter is to further the chartered objectives for which the ACI was organized; to further education and technical practice, scientific investigation, and research by organizing the efforts of its members for a non-profit, public service in gathering, correlating, and disseminating information for the improvement of the design, construction, manufacture, use and maintenance of concrete products and structures. This Chapter is accordingly organized and shall be operated exclusively for educational and scientific purposes.

Objectives of ACI-Malaysia are:

- ACI is a non-profitable technical and educational society formed with the primary intention of providing more in-depth knowledge and information pertaining to the best possible usage of concrete.

- To be a leader and to be recognized as one of Malaysia's top societies specializing in the field of concrete technology by maintaining a high standard of professional and technical ability supported by committee members comprising of educators, professionals and experts.

- Willingness of each individual member/organization to continually share, train and impart his or her experience and knowledge acquired to the benefit of the public at large.

Past Presidents

1997 - 1998
Ir. Tae Ah Heng
(Protem)

1998 - 2000
Ir. Dr. Kribanan G. Naidu

2000 - 2002
The Late Ir. Dr. Norzan

2002 - 2004
Ir. Soo Thong Phor

2004 - 2006
Mr. Seow Aik Guan

2006 - 2008
Ir. Boone Lim

2008 - 2010
Ir. Parnam Singh

2010 - 2012
Ir. Ng Kok Seng

2012 - 2014
Dr. Zack Lim

2014 - 2016
Dr. Zack Lim

2016 - 2018
Ms. Serina Ho

2018 - 2020
Prof. Dr. Sudharshan N. Raman

2020 - 2022
Mr. Martin David

2022 - Present
Mr. Martin David

Management for 2022-2024

Board of Directions (BOD) 2022-2024

President:
Mr. Martin Gerald Joachim David

Director 1:
Mr. Mike Lim Wey Peow

Director 2:
Prof. Dr. Hamidah Bt Mohd Saman

Secretary:
Mr. Oscar Teng Ri Hao

Treasurer:
Mr. Chris Yong Hoe Chern

Immediate Past-President:
Assoc. Prof. Dr. Sudarshan N. Raman

Internal Auditor:
Dr. Zack Lim Eng Hock

Membership Subscription 2022

Gentle reminder that 2021 subscription is due.

Kindly note that payment can be made as follows:
Bank : **Hong Leong Bank Berhad**
Account Number : **291 0002 0936**
Account Name : **American Concrete Institute – Malaysia Chapter**

Once payment has been made, it is important to send
Remittance Slip / Deposit Advice / Bank Transfer Receipt
*to our **Administrative Office** for confirmation, via these channels:*
WhatsApp: **+60 (14) 2207 138** or
E-mail: **admin@acimalaysia.org.my**

Digital Membership Certificate 2022

Members who have paid their subscription will receive their digital membership certificate. See sample below.

American Concrete Institute
Malaysia Chapter

Membership Certificate

This is to certify that

"NAME"

is a

Associate Member

of the

American Concrete Institute Malaysia Chapter

Valid through 2022

Membership No. A0000

Martin David
President (2022-2024)

American Concrete Institute
Malaysia Chapter

Membership Certificate

This is to certify that

"ORGANIZATION NAME"

is a

Corporate Member

of the

American Concrete Institute Malaysia Chapter

Valid through 2022

Membership No.O0000

Martin David
President (2022 2024)

American Concrete Institute
Malaysia Chapter

Membership Certificate

This is to certify that

"STUDENT NAME"

is a

Student Member

of the

American Concrete Institute Malaysia Chapter

Valid through 2022

Membership No. S0000

Martin David
President (2022 2024)

Internship Programme For ACI Student Members

(Subject to Terms & Conditions Apply by Companies)

Company Name	Company Address	Person To Contact	Business Involved
PLYTEC FORMWORK SYSTEM INDUSTRIES SDN BHD	No. 19, Jalan Meranti Permai 3, Meranti Permai Industrial Park, Batu 15, Jalan Puchong, 47100 Puchong, Selangor.	012 - 691 2883 (Mr.Louis Tay)	BIM Engineering Specialist, CME Project Delivery, IBS & Prefabrication Construction.
CRT SPECIALIST (M) SDN BHD	E5-5-25, IOI Boulevard, Jalan Kenari 5, Bandar Puchong Jaya, 47170 Puchong, Selangor.	012 - 313 5991 (Mr.James Lim)	Waterproofing Work, Concrete Repair & Strengthening, Injection & Grouting.
REAL POINT SDN BHD	No. 2, Jalan Intan, Phase NU3A1, Nilai Utama Enterprise Park, 71800 Nilai, Negeri Sembilan.	016 - 227 6226 (Mr.Chris Yong)	Concrete Admixture Production.
JKS REPAIRS SDN BHD	Star Avenue Commercial Center, B-18-02, Jalan Zuhal U5/178, Seksyen U5, 40150 Shah Alam.	017 - 234 7070 (Mr.Kathiravan)	Structural Repair Works, Structural Strengthening, Waterproofing System, Injection & Sealing, Concrete Demolition Works, Protective Coating For Concrete And Steel.
ZACKLIM FLAT FLOOR SPECIALIST SDN BHD	70, Jalan PJS 5/30, Petaling Jaya Commercial City (PJCC), 46150 Petaling Jaya, Selangor.	603 - 7782 2996 (Mr.Zack Lim)	Concrete Flatfloors.
UFT STRUCTURE RE-ENGINEERING SDN BHD	No 46, Jalan Impian Emas 7, Taman Impian Emas, 81300 Skudai Johor.	012 - 780 1500 (Mr.Lee)	Structural Repair, Construction Chemical, Carbon Fibre Strengthening, Protective Coating, Industrial Flooring, Soil Settlement Solution, Civil & Structure Consultancy Services, Civil Testing & Site Investigation.
SINCT-LAB SDN BHD	No 46, Jalan Impian Emas 7, Taman Impian Emas, 81300 Skudai Johor.	012 - 780 1500 (Mr.Lee)	Structural Repairing, CFRP Strengthening, Site Investigation, Civil Testing, Soil Settlement Solution, Civil And Structural Design And Submission.
STRUCTURAL REPAIRS (M) SDN BHD	No. 1&3, Jalan 3/118 C, Desa Tun Razak, 56000 Wilayah Persekutuan, Kuala Lumpur	012 - 383 6516 (Mr.Robert Yong)	Carbon Fiber Reinforced Polymer System, Sealing Cracks With Resin Injection, Re-Structure Repairs and Upgrade, Diamond Wire & Diamond Blade Sawing System, Diamond Core Drilling, Non-Explosive Demolition Agent.

Important Notes:

i) ACI Malaysia is only a platform for our members to advertise for interns.
ii) All application to be made direct to companies and would be subject to their terms and conditions.

ARTICLE

Sustainable Road Construction: Current Practices and Realising the Future Pavement

Muhammad Faheem Mohd Tahir[1,2], Mohd Mustafa Al Bakri Abdullah[1,3], Shayfull Zamree Abd Rahim[2,3] and Mohd Rosli Mohd Hassan[4]

[1]Faculty of Chemical Engineering & Technology, Universiti Malaysia Perlis, Perlis, Malaysia.

[2]Center of Excellence Geopolymer and Green Technology (CEGeoGTech), Universiti Malaysia Perlis (UniMAP), Perlis, Malaysia.

[3]Malaysia Geopolymer Society (MyGeopolymer), Universiti Malaysia Perlis (UniMAP), Perlis, Malaysia.

[4]Faculty of Mechanical Engineering & Technology, Universiti Malaysia Perlis, Perlis, Malaysia.

Abstract

Global arterial networks of roads tend to become more prevalent every year, serving as a symbol of development for some but leaving a growing scar on the landscape for others. In Malaysia alone, millions of kilometres of asphalt pavement exist, a material that is not particularly eco-friendly or sustainable. However, Malaysia, along with many other countries, continues to construct and replace the same types of roads annually, following a centuries-old fundamental layout. Despite humanity's persistent road-building practices, there is no doubt that improvements to asphalt pavement are achievable. Recently, researchers have begun to focus on various enhancements that could enhance roadways in terms of safety, noise reduction, and environmental friendliness. Examples of such modifications include altering the aggregates and binders used in the pavement, as well as incorporating recycled materials. Additionally, adjusting the pavement's stiffness could potentially enhance the performance of vehicles using the road. These adjustments have the potential to significantly reduce CO2 and other pollution emissions. This article delves into the current practices of road construction in Malaysia and explores the future of road pavement, aiming to create a more sustainable and environmentally friendly infrastructure.

Keyword: Pavement; geopolymer; construction materials.

1. Introduction

The ongoing evolution of transport networks addresses the challenges associated with achieving people's objectives. It plays a crucial role in enhancing accessibility, mobility, and economic activity in every country [1]. However, the rapid growth of transportation networks raises concerns due to its significant impact on environmental quality and highway safety. Roads have a finite lifespan and are subject to deterioration caused by the weight and impact of vehicles as well as the surrounding environment. As the economy and transportation infrastructure continue to expand, there will be an increase in the number of private and commercial vehicles on the road [2]. This will result in both external and internal damage to the roads, potentially compromising the safety of other road users.

Pavement deterioration can manifest in various ways, including edge defects, bleeding or flushing, deformation, disintegration, polished aggregate, and cracking. A previous study conducted by Fares et al. [3] has highlighted that damaged pavement poses risks to drivers and increases the likelihood of accidents. For example, encountering a substantial pothole on the road can lead to a collision. The impact may cause tire damage, leading to a loss of control and a potential collision with another vehicle. Malaysia, as a growing nation, is currently grappling with the challenges of increasing car numbers and issues related to overloaded vehicles. The combination of escalating traffic volumes and inadequate maintenance levels accelerates the deterioration of road infrastructure, surpassing anticipated timelines. Hence, enhancing the capabilities and effectiveness of pavement construction would not only benefit road users in terms of safety and comfort but also other domains such as road inventory and asset management, traffic operations, and economic growth.

2. Conventional Malaysia Road Pavement

The first bituminous or flexible pavements were constructed in Malaysia prior to the Second World War. During that time, road pavements were built using block stone pitching on a sub-base of sand or laterite, which was coated with tar or bitumen-stabilised aggregate [4]. Following the war, crushed stone road bases and sand sub-bases with dense bituminous surfacing have been employed for constructing road pavements. Presently, this construction technique continues to be utilised.

The road pavements have been consistently upgraded and maintained to ensure the smooth operation of the road network. Naturally, the road networks of major trade routes have received more attention than others. Consequently, the pavement on the roadways along major routes is thicker compared to that on minor roads. Despite regular repairs and maintenance, there was often a lack of record-keeping regarding their condition and the type of work carried out. Most of the completed upgrading projects were either unplanned or planned using techniques borrowed from various Western nations. It was only in 1974, when KAMPSAX International conducted a Benkelman Beam study of 2291km of Federal and State highways, that an engineering-based road management system was adopted in Malaysia [4].

3. From Flexible to Rigid Road Pavement

The fundamental principles of Roman road design remain applicable in the present day. Generally, significant layers of compacted granular materials are placed atop thick pavement layers to facilitate the transportation of traffic loads to the underlying bedrock or soil. Concrete, comprising aggregates such as sand, pebbles, and gravel bound together with cement, or "asphalt concrete," where sand and gravel are held together by a dark, viscous petroleum byproduct called asphalt, are the two primary materials utilised in the construction of contemporary pavement.

Despite cement concrete often being more durable and rigid than asphalt pavements, it is typically more expensive as well. Therefore, it is not surprising that approximately 94% of paved roads in Malaysia are covered with asphalt concrete or other forms of flexible pavement. This is primarily due to the fact that, in many states, the department of transportation prioritizes pavement materials based on initial costs rather than considering maintenance expenses [5].

The advantages of softer pavement, including improved safety for cyclists and pedestrians, are undeniable. However, flexibility can pose challenges for road traffic. When a large vehicle travels over asphalt or concrete, a depression similar to the hollow left by someone bouncing on a trampoline is formed on the road. This negatively impacts the vehicle's fuel consumption and leads to increased CO2 emissions, as more energy is required to overcome the depression. Figure 1 illustrates that nearly all countries employ similar (though not identical) criteria to assess the suitability and implement multilayer technology for road construction.

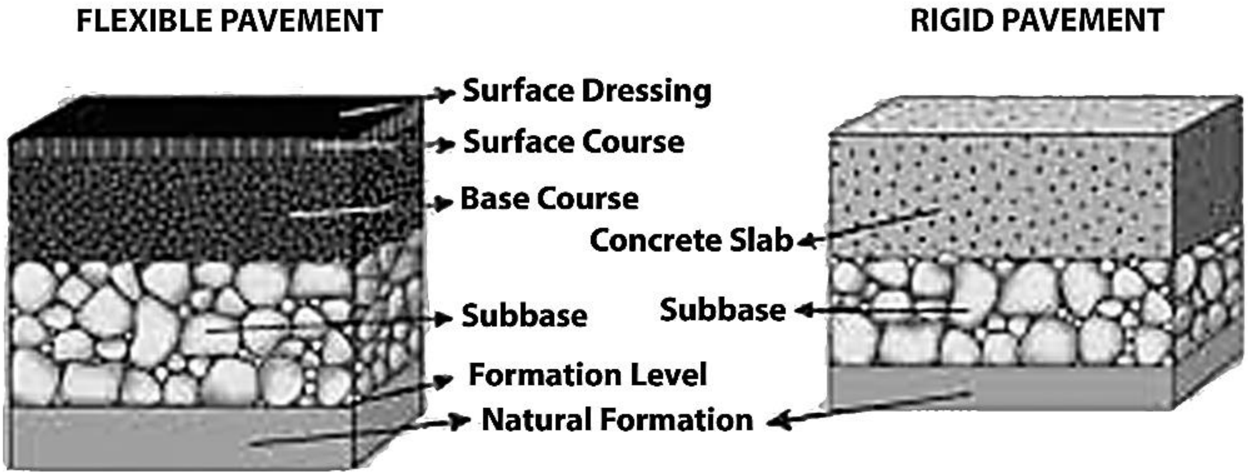


Figure 1: The layers of a typical pavement

4. Reusing waste materials in road pavement construction

The development of sustainable infrastructure holds paramount importance in numerous developed and emerging nations. Across the globe, multiple governments, academic institutions, and paving businesses are conducting research on the utilization of sustainable alternative materials. Products derived from recycled construction and demolition waste (C&D waste) are gaining increasing popularity worldwide. Recent research on the use of recycled materials in construction applications suggests that a certain percentage of these recycled materials can be employed in ecologically friendly pavements, roads, pavement bases, and subbase applications [6].

Waste materials can be classified as surplus or non-essential items that are directly associated with human activities, the construction sector, or industrial sectors [7]. In compliance with the 1992 agreement, all jurisdictions have established comprehensive environmental legislation, The objective is to enhance resource efficiency, minimize the environmental impact of waste disposal, improve hazardous waste management, and prevent waste generation and remediation issues [8]. The Environmental Protection Law of 1970 stipulates that all wastes must be handled according to the "waste class" illustrated in Figure 2. Therefore, it is essential to explore the utilisation of recycled materials.

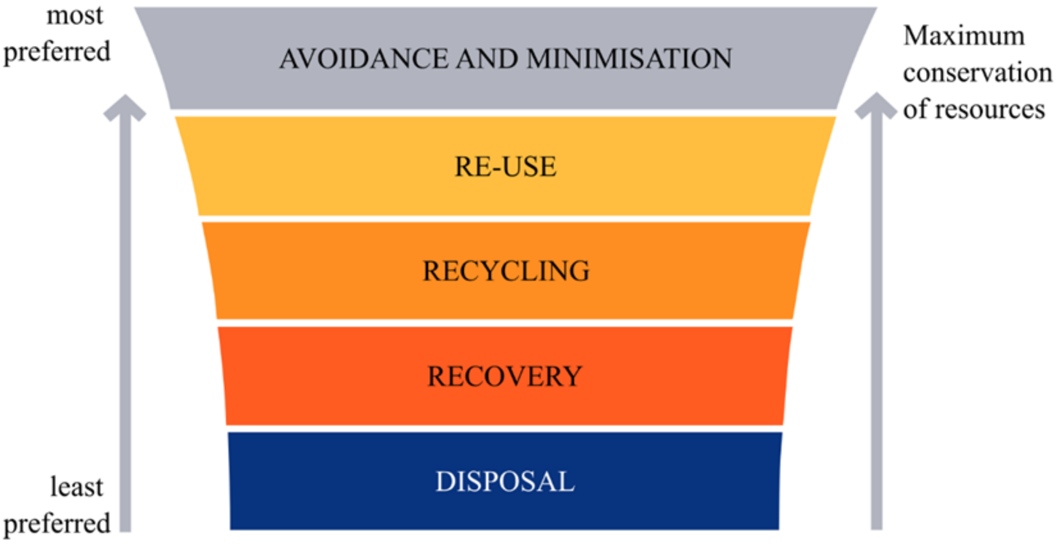


Figure 2: Waste hierarchy [8].

Recycled materials can help reduce construction waste deposited in landfills, extend the lifespan of non-renewable rock resources, and lower the cost of constructing roadway pavement [9]. One of the innovations that has promoted the use of recycled materials for sustainable infrastructure is geopolymer. Cement is commonly used as a binder in rigid pavement construction. Geopolymer, on the other hand, has the potential to compete with cement as an alternative binder for producing environmentally friendly road pavement in the future.

4. Geopolymer as a future road pavement

The primary raw materials used in the production of geopolymers are alkali-activated aluminosilicates, which can be by-products or natural resources with high concentrations of silica and alumina [10]. Geopolymer is formed through various chemical processes, including polycondensation, diffusion, hardening, and dissolution. It is important to note that the alkaline activator mentioned is not an alkali-activated material (AAM), which is an inferior substitute for geopolymer made from calcium hydrate [11]. Geopolymer is not a hydrate as water does not contribute to its structural formation. The term "alkaline activator" refers to an alkaline solution that breaks the aluminosilicate bond and releases silica and alumina, which are primarily present in the source materials. Since Davidovits introduced the geopolymer technology and geopolymerization process in the early 1978, researchers from around the world have been attracted to studying various aspects of its synthesis process, physical properties, machinery, and durability characteristics.

In comparison to conventional Portland cement, the geopolymer technology developed in recent decades has the potential to create a cleaner and more environmentally friendly alternative cement [12]. Pioneering advancements have been made, and geopolymer chemistry, synthesis, and manufacturing have expanded to the point where they can now be produced and marketed as green technologies. These are expected to be highly effective options for transforming industrial waste into durable construction materials with superior mechanical strength. Previous research demonstrates the exceptional mechanical and physical properties of a specific binder known as fly ash-based geopolymer, which often surpass those of traditional materials like regular Portland cement [13-15]. Moreover, the use of fly ash as a raw material for large-scale geopolymer production can have significant positive impacts on both the economy and the environment [16].

Similar to conventional concrete mix designs, mechanical parameters such as compressive strength, bending strength, and tensile strength can be examined. This showcases the significant potential of fly ash-based geopolymers for durable pavement concrete. To achieve higher compressive strength, it is crucial to study parameters that influence compressive strength, such as binder ratio, molar concentration, curing temperature, slump, bending and splitting tensile strength, elastic modulus, and chemical ash activity. Table 1 presents the physical and mechanical parameters of geopolymer concrete, along with the standard testing procedure.

Table 1: Summary properties of geopolymer

Standard Testing Method	Concrete Properties	Requirement
ASTM C138 [119]	Density	2,200 to 2,600 Kg/m^3 [120]
ASTM C191 [122]	Setting Time	3 to 5 hours [140]
ASTM C1437 [128]	Workability	> 150 ± 10 mm Ø [129]
ASTM C109/C109M [134]	Compressive Strength	28 MPa at 28 days compressive strength [141]

7. Conclusion

The socioeconomic and environmental issues we face today are inherent in modern living. One crucial element of transportation infrastructure is the road surface, which is directly associated with the transportation industry. The production and usage of road surfaces have direct implications for current environmental and socioeconomic impacts. Roads contribute significantly to global carbon dioxide emissions. Despite its environmental effects, pavement also brings positive economic benefits and plays a vital role in the community. It fosters social harmony, economic stability, and environmental sustainability, benefiting individuals and society as a whole.

The term "sustainable" is essential to mention as it pertains to the overall progress of the environment, economy, and society. It is crucial to embrace and implement sustainable solutions, especially in industries such as transportation that contribute to the ongoing socio-economic and environmental challenges. Road sustainability aims to mitigate the associated environmental impacts in order to meet societal demands, aspirations, and economic constraints.

It becomes evident that there are numerous possibilities for sustainable paving materials when considering all relevant aspects. Recycling and the utilization of waste and byproducts offer a variety of resources, particularly due to their minimal environmental impact, in addition to their overall social value. While some of these concepts are intriguing and can be immediately implemented, others require further research. The first step towards achieving sustainable development goals is to utilize sustainable materials without compromising the quality of the road surface.

References

1. Jarboui, S.A.M.I., Pascal, F. and Younes, B., 2013. Public road transport efficiency: A stochastic frontier analysis. Journal of Transportation Systems Engineering and Information Technology, 13(5), pp.64-71.
2. Shahid, M.A., 2019, April. Maintenance management of pavements for expressways in Malaysia. In IOP Conference Series: Materials Science and Engineering (Vol. 512, No. 1, p. 012043). IOP Publishing.

3. Fares, H., Shahata, K., Elwakil, E., Eweda, A., Zayed, T., Abdelrahman, M. and Basha, I., 2012. Modelling the performance of pavement marking in cold weather conditions. Structure and Infrastructure Engineering, 8(11), pp.1067-1079.
4. M. S. Hasim, A. Mutalif, Ir. Koid Teng Hye, A. Fauzi, Ir. M. Shafii; 1994 ; Interim Guide to Evaluation and Rehabilitation of Flexible Road Pavements ; Institute Keija Raya Malaysia (IKRAM).
5. Y. Qiao et al., Flexible pavements and climate change: A comprehensive review and implications. Sustainability 12, 1057 (2020).
6. T. Park, Application of construction and building debris as base and subbase materials in rigid pavement, J. Transp. Eng. 129 (5) (2003) 558–563.
7. W. Jiang, Y. Huang, A. Sha, A review of eco-friendly functional road materials, Constr. Build. Mater. 191 (2018) 1082–1092.
8. Environment Protection and Heritage Council (EPHC), National Waste Report 2010, Prepared for the Department of the Environment, Water, Heritage and the Arts, 2010.
9. Francesco Colangelo, Ilenia Farina, Marta Travaglioni, Cinzia Salzano, Raffaele Cioffi, Antonella Petrillo, Eco-efficient industrial waste recycling for the manufacturing of fibre reinforced innovative geopolymer mortars: Integrated waste management and green product development through LCA, J. Clean. Prod., 312 (2021) 127777.
10. P. Duxson, A. Fernandez-Jimenez, J.L. Provis, G.C. Lukey, A. Palomo, J.S.J. van Deventer, Geopolymer technology: The current state of the art, J. Mater. Sci. 42 (2007) 2917–2933.
11. A. Hassan, M. Arif, M. Shariq, Use of geopolymer concrete for a cleaner and sustainable environment – A review of mechanical properties and microstructure, J. Clean. Prod. 223 (2019) 704–728.
12. S. Miraldo, S. Lopes, F. Pacheco-Torgal, A. Lopes, Advantages and shortcomings of the utilization of recycled wastes as aggregates in structural concretes. Constr. Build. Mater. 298, (2021) 123729.
13. P. Chindaprasirt, C. Jaturapitakkul, W. Chalee, U. Rattanasak, Comparative study on the characteristics of fly ash and bottom ash geopolymers, Waste Manag. 29 (2) (2009) 539–543.
14. S. Horpibulsuk, C. Suksiripattanapong, W. Samingthong, R. Rachan, A. Arulrajah, Durability against wetting–drying cycles of water treatment sludge–fly ash geopolymer and water treatment sludge–cement and silty clay–cement systems, J. Mater. Civ. Eng. 28 (1) (2016) 04015078.

15. P. Sukmak, P. De Silva, S. Horpibulsuk, P. Chindaprasirt, Sulfate resistance of clay-portland cement and clay high-calcium fly ash geopolymer, J. Mater. Civ. Eng. 27 (5) (2015) 04014158.
16. M. Kheradmand, Z. Abdollahnejad, F. Pacheco-Torgal, Performance of a fly ash geopolymeric based binder with calcium hydroxide, Portland cement and metakaolin as additives. Open J. Civ. Eng. 12(1) (2018).

Reprint from CI Magazine, Volume 39, No 2, Page 38-44

Nano-Modified Fly Ash Concrete

Field trial of mixtures developed as repair materials

by Ahmed A. Ghazy, Mohamed T. Bassuoni, Ahmed Shalaby, and Rod Hamilton

Some rapid-setting repair materials for concrete pavements do not achieve their target service lives, resulting in significant economic and social losses.1 This is particularly critical, as the U.S. Federal Highway Administration estimates that $85 billion in annual capital investment up to 2028 is needed to improve the physical condition of existing road assets sufficiently to achieve the Department of Transportation's benchmark for ride quality.2

Partial depth repair (PDR) of concrete pavements is a rehabilitation technique used to restore pavements with localized surface distress such as spalls and wide cracks. PDR is normally limited to a maximum of 1/3 the slab thickness.3 Often, the selection of the repair material is based on the allowable lane closure time, which is linked to the strength development of the material over time, so PDR materials typically include accelerators and Type III cement or proprietary rapid-setting binders. However, this approach may not necessarily lead to selecting the most compatible and durable repair product. Some high-early-strength cementitious repair materials have sufficient strength at early age; however, many of these materials are vulnerable to cracking, poor bonding, and premature deterioration due to incompatibility with the existing (parent) concrete pavement or their susceptibility to thermal gradients and autogenous shrinkage.1,4,5

The University of Manitoba, in collaboration with the City of Winnipeg, MB, Canada, recently developed an owner's guide for PDR applications. The guide includes a list of approved PDR concretes (in-house mixtures) that provide adequate early-age and long-term performance, with optimized cost and appropriate service life.3

Nanomaterials have been proven to accelerate hydration, setting time, and strength development; improve mechanical properties; and reduce total shrinkage as well as permeability. The latter benefits can contribute to improving the durability and longevity of concrete.4,6-10 In the PDR project,4 nanosilica was used to produce nano-modified fly ash concrete (NMFC) as a repair material. The repair mixtures comprised fly ash (Class F) to be compatible with concrete pavement mixtures used in Manitoba, where 15% fly ash is typically used. NMFC mixtures produced in the laboratory achieved a reasonable balance of early-age and long-term behavior, as demonstrated by setting time, strength development, compatibility/bonding, and resistance to infiltration of fluids and salt-frost scaling.4 Hence, they have been included in the guide for PDR of concrete pavements for Winnipeg.3 This article reports on the first field trial of NMFC for PDR of transverse joints located on a major urban arterial road in Winnipeg.

Application

Materials

General use (GU) portland cement and Class F fly ash, which meet the requirements of CAN/CSA-A300111 standard, were used as the main components of the binder. In addition, a commercial nanosilica sol (50% solid content of SiO_2 dispersed in an aqueous solution) was incorporated in all binders. Table 1 lists binder properties.

Four NMFC mixtures were prepared. Two of the mixtures included a nonchloride accelerator complying with ASTM C494/C494M Type E and shown by trials to be compatible with the nanosilica and the high-range water-reducing admixture (HRWRA) used in the PDR mixtures. Locally available aggregates were used. The coarse aggregate was natural gravel with maximum size of 9.5 mm (3/8 in.), specific gravity of 2.65, and absorption of 2%. The fine aggregate was well-graded river sand with fineness modulus of 2.9, specific gravity of 2.53, and absorption of 1.5%. The HRWRA was based on polycarboxylic acid (complying with ASTM C494/C494M Type F) and was added to maintain a slump ranging from 100 to 150 mm (4 to 6 in.). An air-entraining admixture conforming to ASTM C260/C260M was used to provide a fresh air content of 6 ± 1%.

Construction procedures

Each test joint was surveyed and prepared in accordance with the protocol in Reference 3 (Fig. 1). A schematic cross section of a repair is shown in Fig. 2. The repaired areas in this field trial (transverse joints; symmetrically cut to the left and right to re-establish new joints) represent a critical scenario for repair applications because they are likely vulnerable to drying/restrained shrinkage (high surface-to-volume ratio) and premature deterioration (entrapment of salt-solutions and freezing-and-thawing cycles).13,14 Therefore, it is desirable for candidate repair materials to exhibit a balance between early-age properties and long-term performance. The NMFC mixtures were designed to satisfy these requirements while providing a cost-effective and sustainable repair alternative.

Table 1:
Properties of GU cement, fly ash, and nanosilica used to produce NMFC

	Cement	Fly ash	Nanosilica
Chemical phases, % of total			
SiO_2	19.21	55.20	99.17
Al_2O_3	5.01	23.13	0.38
Fe_2O_3	2.33	3.62	0.02
CaO	63.22	10.81	—
MgO	3.31	1.11	0.21
SO_3	3.01	0.22	—
Na_2O_{eq}	0.12	3.21	0.20
Physical properties			
Specific gravity	3.15	2.12	1.40
Mean particle size, μm	13.15	16.56	35×10^{-3}
Fineness, m^2/kg	390*	290*	80000†
Viscosity, Cp	—	—	8
pH	—	—	9.5

*Blaine fineness

†Nanosilica fineness was determined by titration with sodium hydroxide[12]

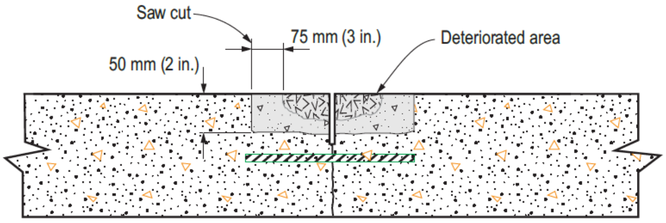


Fig. 2: Configuration of the repair cross section

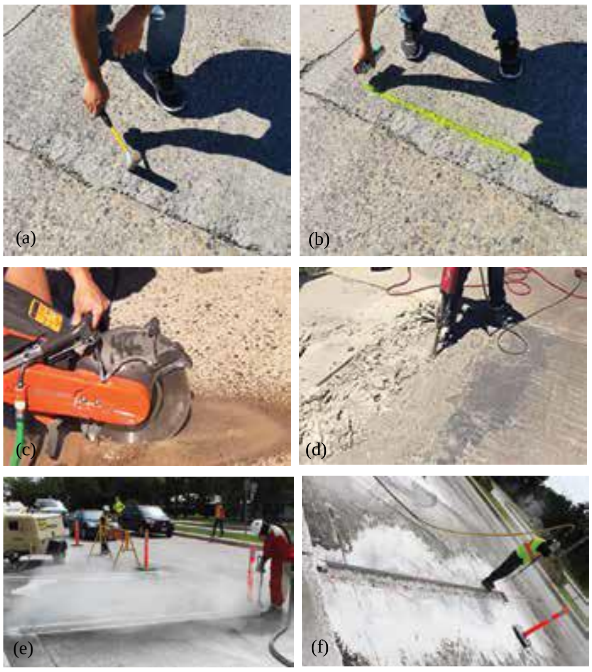


Fig. 1: Preparation of a transverse joint for partial depth repair: (a) the extent of deterioration was determined by "sounding" the concrete; (b) the boundary of the delamination was marked; (c) about 75 mm (3 in.) beyond the boundary, the pavement was sawcut to a minimum depth of 50 mm (2 in.); (d) the deteriorated concrete was removed with a demolition hammer; (e) the repair area was shot blasted to remove loose particles; and (f) remaining residue was removed using a compressed air wand.

Two concrete mixtures with normal setting times (designated as N) were prepared with two dosages of fly ash (22.5% and 30% replacement by mass of the total binder comprising GU cement and fly ash—385 kg/m3 [648 lb/yd3]). Nanosilica was added to the mixtures at a dosage of 6% by mass of the base binder (a solid content of 23 kg/m3 [39 lb/yd3]). In addition, two corresponding rapid-setting concrete mixtures (designated as R) were prepared with an accelerating admixture. The proportions of all mixtures are shown in Table 2.

To improve quality, efficiency, and productivity of the repair process, the constituents were prepackaged in the laboratory and delivered to the site (Fig. 3). The binders were packaged in heavy-duty polyethylene lined bags, ach yielding 15 L (0.53 ft3) with the aggregate. The water, nanosilica, and admixtures were packaged together in sealed containers. Materials were mixed in a portable concrete mixer at 60 revolutions per minute with a 90 L (3 ft3) lift/rotating drum. The mixing sequence is shown in Fig. 4. Roughly two 60 L (2 ft3) batches were needed for each area.

Table 2: Proportions of NMFC mixtures

Mixture ID	Cement, kg/m^3	Fly ash, kg/m^3	Nanosilica*, kg/m^3	Water, kg/m^3	Coarse aggregate, kg/m^3	Fine aggregate, kg/m^3	HRWRA*, kg/m^3	Accelerator*, kg/m^3	Estimated cost, Can$/m^3
NF22.5	298	87	23	154	830	830	1.8	0	250
NF30	269	116	23	154	830	830	1.6	0	230
RF22.5	298	87	23	154	830	830	1.4	3.1	275
RF30	269	116	23	154	830	830	1.2	3.0	255

*Nanosilica, HRWRA, and accelerator were in liquid form with solid contents of 50%, 70%, and 45%, respectively. Note: 1 kg/m^3 = 1.7 lb/yd^3

Fig. 3: Prepackaged constituents for NMFC mixture NF30

Binder(cement and fly ash)

Liquid phase (water, nanosilica, and admixtures)

Aggregates(natural gravel and sand)

Fig. 4: Sequence of mixing for the NMFC repairs: (a) liquid components (water, nanosilica, and admixtures) were stirred vigorously at 1800 to 2600 rpm for 45 seconds; (b) about 15% of the liquid was added to the aggregates while mixing for 30 seconds; (c) cement and fly ash were blended with the aggregates and mixed in the mixer for 60 seconds; (d) the remaining liquid was added and mixing continued for 2 minutes; and (e) the mixture was ready for placement

The NMFC repairs were made as shown in Fig. 5.

Fig. 5: After a joint had been prepared for a partial depth repair (Fig. 1 and 2): (a) the repair area was moistened; (b) a polyethylene joint former was installed at the original joint location; (c) the repair area was slightly overfilled, the mixture vibrated using a pencil vibrator, and the surface was finished with hand trowels level with the existing pavement; and (d) two coats of white-pigmented curing compound were sprayed over the patched areas as soon as bleed water evaporated from the surface

Mixture tests

The following tests were performed to assess the quality of the NMFC repair mixtures:

- Slump and slump loss per ASTM C143/C143M, “Standard Test Method for Slump of Hydraulic-Cement Concrete”;
- Air content per ASTM C231/C231M, “Standard Test Method for Air Content of Freshly Mixed Concrete by the Pressure Method”;
- Temperature per ASTM C1064/C1064M, “Standard Test Method for Temperature of Freshly Mixed Hydraulic-Cement Concrete”;
- Strength per ASTM C39, “Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens.” Test cylinders were prepared during field placement and kept outside the laboratory under similar climatic conditions to that of the repair patches. Tests were made at 16 hours, and 1, 3, and 28 days;
- Penetrability (at 28 days) per ASTM C1202, “Standard Test Method for Electrical Indication of Concrete’s Ability to Resist Chloride Ion Penetration” (RCPT). Cylinders were prepared and cured similar to those used for compressive strength tests. After completing the RCPT, the specimens were axially split and sprayed with 0.1 M silver nitrate solution, which forms a white precipitate of silver chloride in approximately 15 minutes, to measure the physical penetration depth of chloride ions15;
- Ultrasonic pulse velocity was measured in therepair areas before opening to traffic (1 day forthe R mixtures and 3 days for the N mixtures)and after 28 days; andVolume stability was measured using simulatedrepairs. Substrates comprised concrete slabs with300 x 260 mm (12 x 10 in.) surface area and 140 mm(6 in.) thickness, produced using mixtures typicalof existing concrete pavement in Manitoba. Slab mixtures had 350 kg/m3 (22 lb/ft3) total binder, with85% GU cement and 15% fly ash, and 0.38 water-to-binder ratio (w/b). After slabs were aged for 4 to6 months to minimize the residual shrinkage, 30 mm(1.2 in.) thick NMFC layers were placed on the top surfaces. Two slabs were produced for each NMFC mixture. The slabs were exposed to hot-dry conditions(40 ± 2°C [104 ± 4°F] and 35 ± 5% relative humidity[RH]), and average shrinkage over time was determined by measuring length change using dial gauge extensometers.

Findings and Discussion

Fresh properties

The properties of fresh NMFC mixtures are listed in Table 3. All NMFC mixtures were below 30°C (86°F) at the time of placement, which met the City of Winnipeg's specifications.16 Also, 30% fly ash addition was effective at reducing the temperature rise during hydration. Incorporation of 22.5 to 30% Class F fly ash helped control the shrinkage of nano-modified concrete as indicated by the absence of surface cracks after 28 days. This can be attributed to its dilution effect (by replacement of the cement component) and balancing the reactivity of nano-silica, especially at early age.4 The average daily temperatures and RH over 28 days after casting were 22°C (72°F) and 82%, respectively, with intermittent rainfall (4 days during the first week), which contributed to improving the curing efficiency of the NMFC. Moreover, the NMFC mixtures retained adequate consistency and cohesiveness up to 30 minutes after initial mixing allowing added flexibility in casting, compaction, and finishing of the repair patches. The incorporation of the accelerator made the initial slump of the R mixtures higher than that of the N mixtures, whereas the residual slump was higher for the N mixtures after 15 and 30 minutes of mixing. This is ascribed to the effect of Type E accelerator, which initially improved the consistency (plasticizing effect), and subsequently shortened the rate of hardening (accelerating effect), as shown in Table 3. Incorporation of a higher dosage of fly ash (30%) had a pronounced effect on improving the consistency up to 30 minutes after mixing due to increasing the volume fraction of paste comprising spherical fly ash particles with slower reactivity. Generally, all the fresh properties of NMFC produced in the field conformed to that of laboratory concrete,4 indicating the success of the prepacking and mixing procedures adopted in this field trial.

Table 3: Properties of fresh NMFC

Mixture ID	Temperature, °C (°F)	Density, kg/m^3 (lb/ft^3)	Slump, mm (in.) Test time, minutes			Air content, %
			0	15	30	
NF22.5	25.5 (77.9)	2225 (139)	105 (4.13)	75 (2.95)	30 (1.18)	7.7
NF30	21.5 (70.7)	2224 (139)	125 (4.92)	90 (3.54)	40 (1.57)	6.8
RF22.5	28.5 (83.3)	2231 (139)	135 (5.31)	55 (2.17)	10 (0.39)	7.3
RF30	27.0 (80.6)	2230 (139)	155 (6.10)	70 (2.76)	25 (0.98)	7.1

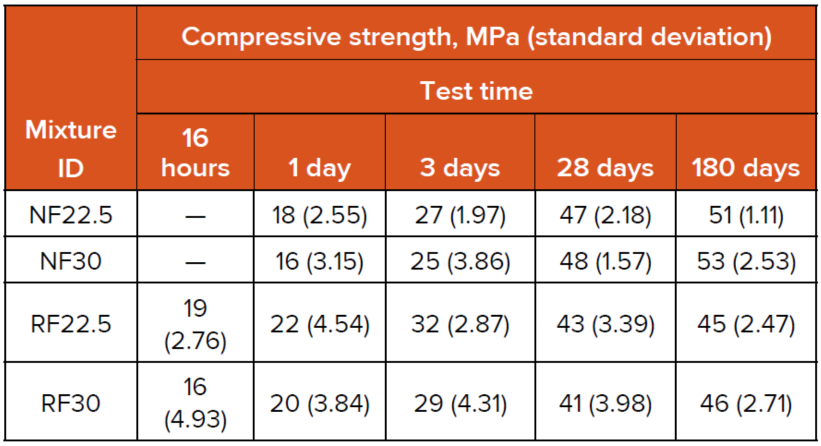
Hardened properties

Compressive strength values for the NMFC cylinders prepared in the field and cured under the same conditions of patched joints at different ages (16 hours and 1, 3, and 28 days) are listed in Table 4. As previously mentioned, the selection of the repair material is typically based on the opening times required for a specific site. Therefore, the R mixtures were designed for an opening time of 1 day, at which the mixtures would reach a compressive strength of at least 15 MPa (3000 psi).3 Comparatively, the N mixtures are recommended for sites where opening to traffic is not required during the first 72 hours.3

The R mixtures gained the target compressive strength after 16 to 24 hours, as shown in Table 4. The average early-age (up to 3 days) strength for the R mixtures increased approximately by 31% in comparison to the N mixtures. This is ascribed to the presence of the accelerating admixture, which sped up the rate of hydration reactions and increased the early-age strength.

On the other hand, the compressive strength of the N mixtures markedly improved at and after 3 days, as these mixtures gained 25 MPa (3630 psi) or more. Hence, the slow rate of strength development for concrete incorporating Class F fly ash was controlled by the addition of a small dosage of nanosilica.

Table 4: Compressive strength of NMFC at different ages



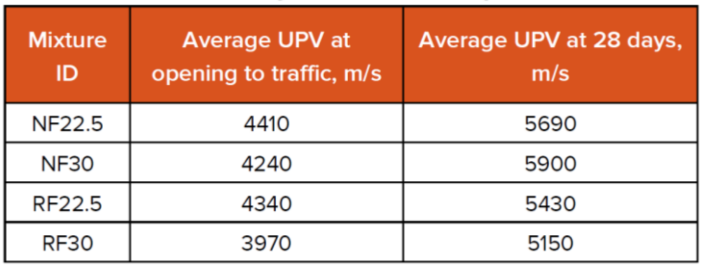
Mixture ID	Compressive strength, MPa (standard deviation)				
	Test time				
	16 hours	1 day	3 days	28 days	180 days
NF22.5	—	18 (2.55)	27 (1.97)	47 (2.18)	51 (1.11)
NF30	—	16 (3.15)	25 (3.86)	48 (1.57)	53 (2.53)
RF22.5	19 (2.76)	22 (4.54)	32 (2.87)	43 (3.39)	45 (2.47)
RF30	16 (4.93)	20 (3.84)	29 (4.31)	41 (3.98)	46 (2.71)

Note: 1 MPa = 145 psi

After 28 days, the compressive strength for all the NMFC mixtures ranged between 41 to 48 MPa (5950 and 6960 psi), which is overlapping with the target range for the parent concrete (40 to 43 MPa [5800 and 6240 psi]), suggesting that the assembly will behave as an integral system owing to compatibility. The compatibility and strength development of the NMFC mixtures in terms of hydration evolution, bonding, and microstructural features were presented in an earlier study.4

Before opening the repaired areas for traffic (after 1 day for R mixtures and 3 days for N mixtures), a total of 40 UPV measurements (indirect mode) were made on each joint to inspect the quality of the repair patches in terms of homogeneity and integrity. In addition, the same procedure was repeated for all patches at 28 days. Indirect measurements were conducted using a coordinate system drawn on the repair surface, as shown in Fig. 6. Repairs for all NMFC mixtures had an average pulse velocity greater than 3500 m/s at the time of opening to traffic (Table 5), indicating that they had adequate uniformity and minimal internal flaws,

Fig. 6: A grid was applied to the surface of a repaired joint to allow locations to be correlated with UPV measurements



Mixture ID	Average UPV at opening to traffic, m/s	Average UPV at 28 days, m/s
NF22.5	4410	5690
NF30	4240	5900
RF22.5	4340	5430
RF30	3970	5150

Table 5: Ultrasonic test velocity data for test repairs

shrinkage cracks, or debonding.17 Moreover, the UPV results at 28 days indicated that all repairs continued to densify over time, as the lowest pulse velocity at 28 days was more than 5100 m/s.

RCPT data for cylinders exposed to the same environmental conditions as the repair patches are listed in Table 6. The chloride penetration depths are shown in Fig. 7. Using the classification recommended in ASTM C1202, all NMFC mixtures had “very low” penetrability, as the charge passed was less than 1000 coulombs. All mixtures also had markedly low chloride penetration depths (less than 10 mm [0.4 in.]), indicating densification of the mixture and discontinuity of the pore structure. The same trends were observed in the laboratory study.4

The shrinkage behavior and the crack patterns after 180 days are presented in Fig. 8. It is conceivable that the degree of cracking was exaggerated by the continual hot-dry exposure. In the field, frequent increases in RH and precipitation would be expected to reduce shrinkage and cracking. The observed early-age shrinkage behavior correlates with early acceleration in the hydration process. Densification and desiccation of the repair materials are likely causes for the notable reduction in shrinkage rate after 28 days. The presence of the accelerator in the R mixtures magnified the shrinkage rates up to 28 days (increased by 9 to 16%) and their total shrinkage at 180 days (increased by 15 to 18%) relative to the corresponding N mixtures. Generally, increasing the fly ash content in the N and R mixtures led to reductions in the rate of shrinkage (an average of 12% up to 28 days and 17% at 180 days). Also, Mixture RF30 had lower intensity of surface cracking compared to RF22.5. The action of the higher dosage of fly ash (30%) can be linked to its dilution effect and slower reactivity at early age, resulting in decreasing the rate of the shrinkage up to 28 days. Moreover, desiccation as well as densification and increased mechanical properties for these mixtures (as indicated in Table 4) resulted in minimal increases in shrinkage after about 140 days.

Table 6:
RCPT results at 28 days

Mixture ID	Charge passed, coulombs	Average penetration depth, mm (standard error)
NF22.5	541	6 (0.46)
NF30	423	5 (0.24)
RF22.5	581	7 (0.32)
RF30	622	9 (0.29)

Note: 1 mm = 0.04 in.

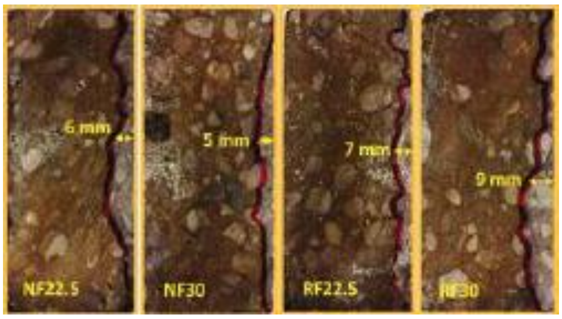


Fig. 7: Whitish precipitates show the average penetration depth of chloride ions for the four NMFC mixtures evaluated in this study (Note: 1 mm = 0.04 in.)

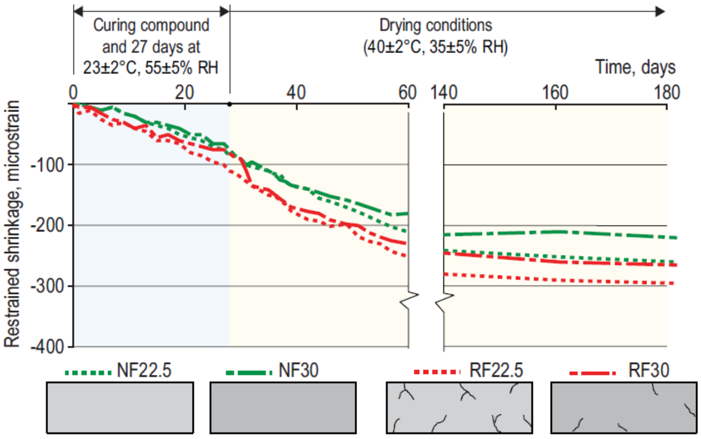


Fig. 8: Restrained shrinkage and crack patterns of the NMFC repair layer in the concrete test slabs. Crack patterns were obtained after specimens had aged 180 days (Note: °C = 0.56°F − 32)

Potential for NMFC

The NMFC mixtures produced and applied in this field trial had reasonable consistency and slump retention suitable for placement and finishing operations. In addition, they achieved the target rate of strength development, homogeneity of elastic behavior, and resistance to ingress of fluids. Whether mixed in the field or the laboratory,4 the uniformity and quality of the NMFC mixtures were comparable.

NMFC shows the potential for allowing transportation agencies to control fresh and/or hardened properties by adjusting the proportions of ingredients. Costs will also be reduced due to the greater use of fly ash as a cement replacement. We estimate that the direct cost of NMFC materials with normal or accelerated setting times will be comparable or about 12% higher, respectively than the cost of normal concrete. Thus, NMFC presents a sustainable and cost-effective option for repair of concrete pavements, with an anticipated measurable impact on reducing life-cycle cost of partial depth repairs due to its projected durability and longevity.3,4 This field trial demonstrated the mixing, placement, and testing procedures of NMFC as a novel repair material for pavements with promising long-term performance.

Acknowledgments

The authors acknowledge the financial support of the Natural Sciences and Engineering Research Council of Canada, University of Manitoba Graduate Fellowship, and the City of Winnipeg. The IKO Construction Materials Testing Facility at the University of Manitoba has been instru-mental to this research.

References

1. Li, M., and Li, V.C., “High-Early-Strength Engineered Cementitious Composites for Fast, Durable Concrete Repair Material Properties,” ACI Materials Journal, V. 108, No. 1, Jan.-Feb. 2011, pp. 3-12.
2. “2013 Report Card for America’s Infrastructure,” American Society of Civil Engineers, Reston, VA, 2013, 119 pp., www. infrastructurereportcard.org (accessed June 21, 2016).
3. “Guide for Partial Depth Repair of Concrete Pavements,” City of Winnipeg, MB, Canada, 2015, 21 pp.
4. Ghazy, A.; Bassuoni, M.T.; and Shalaby, A., “Nano-Modified Fly Ash Concrete: A Repair Option for Concrete Pavements,” ACI Materials Journal, V. 113, No. 2, Mar.-Apr. 2016, pp. 231-242.
5. Soliman, H., and Shalaby, A., “Characterizing the Perfor -mance of Cementitious Partial-Depth Repair Materials in Cold Climates,” Construction and Building Materials, V. 70, Nov. 2014, pp. 148-157.
6. Collepardi, M.; Collepardi, S.; Skarp, U.; and Troli, R.,“Optimization of Silica Fume, Fly Ash and Amorphous Nano-Silica in Superplasticized High-Performance Concrete,” Eighth CANMET/ACI International Conference on Fly Ash, Silica Fume, Slag, and Natural Pozzolans in Concrete, SP-221, American Concrete Institute, Farmington Hills, MI, 2004, pp. 495-506.
7. Sobolev, K., and Ferrada-Gutiérrez, M., “How Nanotechnology Can Change the Concrete World: Part I,” American Ceramic Society Bulletin, V. 84, No. 10, 2005, pp. 14-17.
8. Gaitero, J.J.; Campillo, I.; and Guerrero, A., “Reduction of the Calcium Leaching Rate of Cement Paste by Addition of Silica Nanoparticles,” Cement and Concrete Research, V. 38, No. 8-9, Aug. 2008, pp. 1112-1118.
9. Flores, I.; Sobolev, K.; Torres-Martinez, L.M.; Cuellar, E.L.; Valdez, P.L.; and Zarazua, E., “Performance of Cement Systems with Nano-SiO2 Particles Produced by Using the Sol-Gel Method,” Transportation Research Record: Journal of the Transportation Research Board, V. 2141, 2010, pp. 10-14.
10. Belkowitz, J.S.; Belkowitz, W.B.; Best, M.A.; and Fisher, F.T., “Colloidal Silica Admixture,” Concrete International, V. 36, No. 7, July 2014, pp. 59-63.

11. CAN/CSA-A3001, "Cementitious Materials for Use in Concrete," Canadian Standards Association (CSA), Mississauga, ON, Canada, 2008.
12. Sears, G.W. "Determination of Specific Surface Area of Colloidal Silica by Titration with Sodium Hydroxide," Analytical Chemistry, V. 28, No. 12, Dec. 1956, pp. 1981-1983.
13. Arribas-Colón, M.; Radliński, M.; Olek, J.; and Whiting, N., "Investigation of Premature Distress around Joints in PCC Pavements: Parts I & II," FHWA/IN/JTRP-2012/25 & FHWA/IN/ JTRP-2012/26, Joint Transportation Research Program, West Lafayette, IN, 2012, 75 pp.
14. Panchmatia, P.; Olek, J.; and Whiting, N., "Joint Deterioration in Concrete Pavements," 4th International Conference on the Durability of Concrete Structures, Purdue University, West Lafayette, IN, USA, 2014, pp. 12-21.
15. Bassuoni, M.T.; Nehdi, M.; and Greenough, T., "Enhancing the Reliability of Evaluating Chloride Ingress in Concrete Using the ASTM C 1202 Rapid Chloride Penetrability Test," Journal of ASTM International, V. 3, No. 3, Mar. 2006, 13 pp.
16. "Specification CW 3310: Portland Cement Concrete Pavement Works," Public Works Department, City of Winnipeg, Winnipeg, MB, Canada, 2014.
17. del Río, L.M.; Jiménez, A.; López, F.; Rosa, F.J.; Rufo, M.M.; and Paniagua, J.M., "Characterization and Hardening of Concrete with Ultrasonic Testing," Ultrasonics, V. 42, No. 1-9, Apr. 2004, pp. 527-530.

Note:
Additional information on the ASTM standards discussed in this article can be found at www.astm.org.

Received and reviewed under Institute publication policies.

ACI member **Ahmed A. Ghazy** is a PhD Candidate at the University of Manitoba, Winnipeg, MB, Canada. He is Vice President of the University of Manitoba Student Chapter – ACI. He is also a research assistant at the Faculty of Engineering, Alexandria University, Egypt. His research interests include durability of concrete, behavior of repair materials, and characterization of microstructure of porous materials.

ACI member **Mohamed T. Bassuoni** is an Associate Professor in the Department of Civil Engineering at the University of Manitoba. He is a member of ACI Committees 201, Durability of Concrete; 236, Material Science of Concrete; 237, Self-Consolidating Concrete; and 241, Nanotechnology of Concrete. His research interests include cementitious materials and durability of concrete.

Ahmed Shalaby is a Professor of Civil Engineering at the University of Manitoba. His research interests include pavement engineering and infrastructure management.

Rod Hamilton is the Manager of the Asset Management Office of the Public Works Department at the City of Winnipeg. His interests include ensuring the City of Winnipeg strives to achieve the best life-cycle cost for its assets.

CASE STUDY

Reprint from CI Magazine, Volume 39, No 1, Page 39-46

From Research to Reality

Can we implement performance-based specifications for durability and longevity of concrete? Will they work?

by Tom Yu, Casimir J. Bognacki, Karthik H. Obla, James K. Hicks, Matthew D. D’Ambrosia, W. Jason Weiss, Tengfei Fu, and Eric R. Giannini

Concrete specifications have historically been prescriptive instructions to the contractor, defining not only mixture proportions but also means and methods. In contrast, performance-based specifications can provide the contractor and concrete producer with incentives to develop innovative concrete mixtures. Because the performance model is an alternative that is more related to how the concrete will perform over its service life, performance specifications can also lead to enhancements in the sustainability of concrete construction.

ACI Committee 329, Performance Criteria for Ready Mixed Concrete, seeks to work with ACI Committees 301, Specifications for Structural Concrete, and 318, Structural Concrete Building Code, to incorporate alternative, performance-based language in those committees’ specification and code documents. Both ACI 301-161 and ACI 318-142 address durability requirements based on exposure classes for freezing-and-thawing, chloride-induced corrosion, and external sulfate attack. These requirements are drawn from, but are not completely consistent with, recommendations in ACI 201.2R, “Guide to Durable Concrete,”3 and are primarily prescriptive in nature—for example, maximum water-cementitious material ratio (w/cm)—and are not correlated to any specific service life. Acceptance of ready mixed concrete per ACI 318-14 and ACI 301-16 primarily remains reliant on measurements of slump, air content, and compressive strength rather than measurable durability performance criteria (for example, permeability, resistivity, and drying shrinkage potential).

Currently, ACI Committee 329 is developing a new guidance document for writing performance-based guide specifications. This may serve as a basis for performance-based language for durability to be added to ACI specifications and codes, including ACI 301 and ACI 318, either by reference or as a supplemental alternative to the current prescriptive approach. ACI Committee 201, Durability of Concrete, is also exploring the development of a model specification or code document for durability that may benefit from the work in progress by ACI Committee 329.

The ACI 301 Specification1 and ACI 318 Building Code2 are particularly important documents because together they often form the basis for model and local building codes and project specifications. An increase in the use of performance-based language in these documents is likely to lead to increased implementation in practice. However, changing these documents and their associated ASTM standards is a rigorous, consensus-based process that demands acceptance by committees balancing the interests of concrete producers, consumers, and the general public. ACI 318, in particular, is tasked with establishing the minimum requirements for structural concrete from a life safety perspective; any changes to the mandatory language document must be in support of that mandate. To implement performance specifications, many groups must be confident that the specifications will result in successful execution. The primary questions are:

- Can the concrete industry implement performance-based specifications?
- Will performance-based specifications ensure durability and longevity?

A panel of experts, several of whom serve on ACI Committee 329, debated these questions during the 123 Forum session at The ACI Concrete Convention and Exposition – Spring 2016 in Milwaukee, WI, on April 18, 2016. Eric Giannini and Tengfei Fu organized and moderated the session. The panelists included Tom Yu, Federal Highway Administration (FHWA); Casimir Bognacki, Port Authority of New York & New Jersey (PANYNJ); Karthik Obla, National Ready Mixed Concrete Association (NRMCA); two consulting engineers—Matthew D'Ambrosia, CTLGroup, and James Hicks, Hicks Engineering; and W. Jason Weiss, Oregon State University. This article is a summation of the ideas presented and discussed by the panelists.

The panel was not in complete agreement on all facets of the implementation of performance-based specifications. Yu discussed FHWA efforts to encourage the implementation of performance-based specifications by state departments of transportation (DOTs). Bognacki and the PANYNJ stated that some degree of prescriptive specifications remain relevant and necessary, and challenged the idea put forth by Yu and Obla that performance-based specifications would encourage innovation and quality control improvements by producers. D'Ambrosia and Hicks discussed opportunities and challenges associated with the development and implementation of performance-based specifications, and Weiss offered a proposed framework for a performance-based approach to specifying durability.

USDOT's Perspective

The U.S. FHWA encourages innovation programs that deploy and promote pavement technologies and practices that improve performance, cost-effectiveness, safety, and user satisfaction. These programs are specifically required by the Moving Ahead for Progress in the 21st Century Act (MAP-21)4 and continued under the Fixing America's Surface Transportation (FAST) Act.5 Durable concrete is essential to achieving long-life concrete pavements. Making durable concrete may involve the use of supplementary cementitious materials (SCMs) and chemical admixtures that can also enhance the sustainability of concrete by reducing the environmental impact and life-cycle costs associated with concrete construction. In many parts of the United States, the use of recycled concrete aggregate (RCA) is under greater consideration for a wider range of projects because of the dwindling supply of quality virgin aggregate. Depending on the quality of the RCA, it may be possible to make concrete meeting desired durability performance targets, even if they are not yet permitted by many project specifications. In fact, many specifications currently in use are not designed to accommodate the wide range of materials combinations capable of producing more durable and sustainable concrete. An elegant solution is to use a performance specification, allowing improvements in durability, cost-effectiveness, and sustainability, while also giving contractors the freedom to be innovative.

The question surrounding performance specifications is whether the tools are available today for implementation. The key to answering this question is recognizing that the ultimate goal is to improve the quality of concrete, not to initially implement a completely performance-based specification. In current practice, only the mechanical properties of hardened concrete (primarily strength) are commonly measured for acceptance. Durability is addressed by specifying certain mixture requirements—for example, the SCM content, cement content, w/cm, and air content. For the most part, this approach works, but such specifications cannot be extended to new materials or new requirements (such as specifying a 50-year service life rather than a 20-year service life). Measuring and specifying durability has long been recognized as an area of weakness in the concrete knowledge base. Both topics have been subjects of active research in recent years. Studies and field trials have successfully demonstrated practical testing procedures that can be used to assess durability, including tests for surface resistivity to evaluate resistance to chloride ingress, and the Super Air Meter (SAM) to characterize the air void structure. While further research is certainly needed, the available tools seem adequate technologies for improving the reliability of achieving durable concrete through the use of performance-type specifications. A performance-type specification uses certain quality characteristics indicative of performance to improve current prescriptive specifications as a step toward true performance-related specifications.

For successful implementation, a performance-type specification has to be practical and acceptable to both state DOTs and industry. To be acceptable to DOTs, performance specifications may need to include some prescriptive elements until it can be proven that concrete can be successfully evaluated using only a few performance measures. To be acceptable to concrete producers and contractors, the testing requirements associated with these measures have to be reasonable. To assist in the implementation of performance specifications for concrete paving mixtures, FHWA will be developing guidance documents and training for state DOTs as well as contractors.

Hybrid Specifications Implemented by PANYNJ

The PANYNJ allows concrete mixture proportions to be determined using a performance-based specification that also includes some prescriptive requirements. As an example, for bridge decks, contractors must submit mixture proportions that meet requirements for:

- Compressive strength;
- Charge passed (less than 1000 coulombs using an accelerated 28-day version of ASTM C1202, “Standard Test Method for Electrical Indication of Concrete’s Ability to Resist Chloride Ion Penetration”); and
- Maximum shrinkage (no more than 0.03% at 28 days per the dry method specified in ASTM C157/C157M,“Standard Test Method for Length Change of Hardened Hydraulic-Cement Mortar and Concrete”).

Although contractors have some flexibility in designing a mixture to meet these performance requirements, a prescriptive component of the bridge deck specifications requires a maximum w/cm of 0.40 and a nominal maximum aggregate size of 1.5 in. (38 mm).

Some might say that this specification is too prescriptive and is not truly performance-based. However, the Port Authority’s experience has been that, without the aforementioned requirements, the concrete mixture provided by producers would be inferior to those that have been obtained using these requirements. The Port Authority also has found that there is little interest or incentive for concrete producers to perform the necessary research with their materials to produce more durable concrete. So, while the Port Authority agrees that a pure performance-based specification is a good idea, it also notes that there are very few concrete producers that have the facilities, staff, and interest in bringing such a specification to fruition.

The PANYNJ view is that acceptance criteria that will result in a durable concrete bridge deck with a predicted service life of 100 years when subjected to chloride exposure (typically, Exposure Class C2 for Port Authority projects) are lacking in the concrete industry. The service life prediction is typically based on models that use diffusivity and permeability of concrete as inputs. The results of testing per ASTM C1202 (often called the rapid chloride permeability test [RCPT]) are typically used to determine concrete permeability. A RCPT result of less than 1000 coulombs is generally accepted as low-permeability concrete. While mixtures are typically evaluated using service life prediction models such as Life 3656 or STADIUM®,7 these software packages have a major flaw—they are only designed to model transport in uncracked concrete. Significant cracking in a bridge deck subjected to deicing chemicals will reduce its service life compared to predictions by these models. It is worth noting that many consultants and agencies do not perform RCPT evaluations during actual construction, with common reasons being that the test is costly and only a few laboratories can perform it. The Port Authority's experience with this test is that it can be used for quality acceptance, when properly specified, and it is not costly to run. For these reasons, the test is specified for acceptance of concrete on Port Authority projects such as bridge decks, where durability is of primary concern. Historical data on Port Authority projects show instances of concrete with compressive strengths greater than 6000 psi (41 MPa) that failed to meet the RCPT requirements of less than 1000 coulombs. This demonstrates that strength and w/cm requirements alone are insufficient for producing low-permeability concrete, particularly when the water content of the concrete is never verified.

The Port Authority also evaluates concrete mixtures during placement using AASHTO T 318, "Standard Method of Test for Water Content of Freshly Mixed Concrete Using Microwave Oven Drying." The water content of fresh concrete is a good indicator of the eventual hardened concrete permeability and drying shrinkage potential, two important properties for predicting and enhancing concrete durability and service life. However, while the test has been shown to be accurate and reproducible when properly done, it is not in common use in the concrete industry.

The Goethals Bridge, a major crossing in the New York City metro area, is now under construction under a Private Public Partnership (3P) contract. In preliminary discussions with the project's consultants and contractors, the Port Authority was disappointed that the model used to predict a service life of 100 years was based on the transport properties of the concrete, but the model ignored the effect of cracking in the deck. Furthermore, there was no acceptance testing recommended during construction to verify that the assumed transport properties of the concrete were being achieved. At the Port Authority's insistence, the deck concrete mixture design required a shrinkage of 0.03% at 28 days, per the dry method in ASTM C157/C157M, and a 1.5 in. nominal maximum aggregate size to minimize cracking potential. RCPT testing was also performed on samples cast from bridge deck concrete delivered to the site to confirm that the assumed transport properties were being achieved.

The concrete industry needs to develop realistic prediction models, concrete mixture proportions, and acceptance criteria for reinforced concrete subjected to chlorides that can more realistically provide a service life of 100 years with minimal maintenance. After these tools are developed, owner agencies such as the Port Authority will be more open to discussions of implementing fully performance-based specifications for durability.

Concrete Industry Perspectives

A 2014 review of project specifications conducted by the National Ready Mixed Concrete Association (NRMCA) revealed the following8:

- In 85% of the reviewed specifications, there was a restrictive limit on the maximum quantity of SCMs. There was no associated exposure condition, such as ACI 318 Exposure Class F3 for cyclic freezing and thawing, that would warrant this limit;
- In 73% of the specifications, there was a limit on the maximum w/cm of concrete mixtures. Again, there was no associated exposure condition which would warrant this limit;
- In 46% of the specifications, there was a requirement for a minimum cementitious material content. With the exceptions of floor slabs or environmental engineering structures, this is not consistent with ACI standards;

- In 27% of the specifications, additional restrictions, beyond those in the pertinent material specifications, were imposed on the type or characteristics of SCMs that could be used; and
- In 25% of the specifications, requirements were imposed on the combined aggregate grading. This requirement does not exist in ACI standards.

A 2012 industry survey by NRMCA reported that the average SCM content in concrete mixtures was 18% of the total cementitious material content, with fly ash constituting average SCM content in concrete mixtures was 18% of the total cementitious material content, with fly ash constituting approximately 80% of total SCM usage.9 Survey respondents indicated that the primary reason for not using higher quantities of SCMs was because of limits prescribed in project specifications. Implementation of performance-based specifications, and the elimination of prescriptive limitations on concrete mixtures, will allow increased use of SCMs. In turn, this will support the development of concrete mixtures better optimized for durability performance, and it will support sustainable construction initiatives. Imposing specification limits for cementitious materials content and w/cm, when not required, can result in concrete mixtures that are not optimized for performance and do not support sustainability initiatives. These two requirements also result in compressive strengths that are higher than specified, thus reducing the incentive to improve concrete quality control. Figure 1 illustrates a poor level of quality control (coefficient of variation greater than 11%) in a project with a minimum cementitious materials requirement. An NRMCA study showed that at the same w/cm, increasing the cementitious materials content of concrete resulted in higher shrinkage and chloride penetrability at similar strengths.10

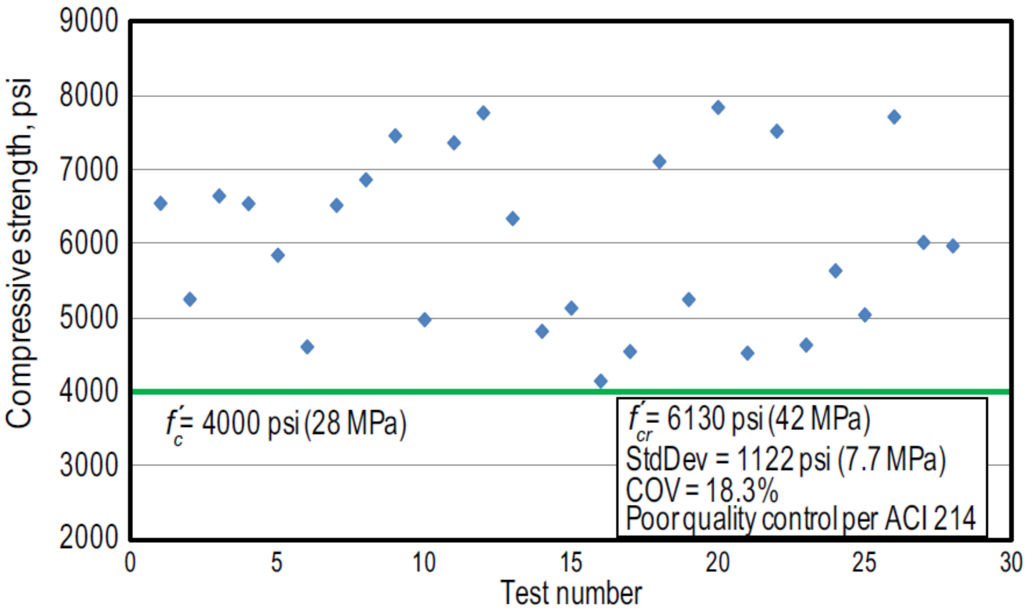


Fig. 1: Variability of compressive strength test results from a project with a specified minimum cementitious materials content requirement (Note: 1 psi = 0.007 MPa)

From an industry perspective, evolution to performance-based specifications for concrete mixtures can occur when:

- The specification writer at a design firm evaluates the firm's current specifications for prescriptive provisions and their purposes relative to a project, eliminates requirements that do not pertain to the project, and proposes performance-based alternatives, if necessary;

- The alternative specification includes basic requirements for concrete in accordance with Chapters 19 and 26 of the ACI 318-14 Building Code and covered in ACI 301-16. The specification should include exposure class for durability, specified strength, and maximum w/cm consistent with the exposure class, nominal maximum aggregate size, air content, slump or slump flow, chloride limit, and temperature limits; and
- These performance requirements may include an evaluation of permeability (per ASTM C1202), shrinkage (per ASTM C157/C157M), alkali-silica reactivity (per ASTM C1778, “Standard Guide for Reducing the Risk of Deleterious Alkali-Aggregate Reaction in Concrete”), sulfate resistance (ASTM C1012/C1012M, “Standard Test Method for Length Change of Hydraulic-Cement Mortars Exposed to a Sulfate Solution”), as well as a thermal control plan for mass concrete. When performance tests and criteria are included, prescriptive provisions should be removed, as over-specification can result in non-optimized mixtures that will not perform as intended.

Performance-based specifications are being adopted for transportation structures, with good success, by various state highway agencies, including Virginia DOT, Illinois DOT, Washington DOT, Vermont DOT, PANYNJ, and New York DOT. Other resources for the evolution to performance include ACI 329R-14, a report on performance-based requirements,11 and ACI 211.5R-14, a report on performance-based mixture submittal.12 The NRMCA has championed the move toward performance-based specifications since 2002. Some of the associated developments include producer quality initiatives, a quality certification program, guide performance specification, guide to improving specifications, a checklist produced in cooperation with the American Society of Concrete Contractors (ASCC), research studies for performance criteria, the Specification-in-Practice (SIP) series, articles, and webinars. Most of these can be accessed from www.nrmca.org/p2p.

Performance-based specifications accelerate the adoption of innovation and establish appropriate responsibility for performance. Concrete producers can apply their knowledge of the materials available to optimize mixtures to meet these specifications. Because performance specifications provide the responsibility and incentives to attain better quality, they incentivize the producer to become more technically proficient and to focus on quality. This can result in reduced time and cost expenditures needed to address project problems, and it can lead to greater confidence in concrete construction in general. Given that all project stakeholders will benefit from their implementation, performance-based specifications are the future for the concrete industry.

Challenges of Implementation of Performance-Based Specifications

From the perspective of a practicing consulting engineer, there are three main challenges to practical implementation of a performance-based specification:

- The project team must understand the performance needs in the context of project costs;
- The project team must ensure that the specification can be practically implemented; and
- The specification must address a realistic and efficient quality control testing program.

First, the owner and design engineering team need to have a firm grasp of the performance they need or want relative to the cost of the project. For example, it is not practical for most projects to require concrete to last hundreds or thousands of years when we only have about 100 years of historical data on reinforced concrete (and less with modern cements and SCMs). This requires unrealistic projections of models and test criteria. Project documents must clearly spell out the definition of service life and all related requirements so that all parties are striving for the same goals. It also is necessary to address mechanisms of deterioration other than corrosion of reinforcing steel, such as alkali-aggregate reactions (AAR), cyclic freezing-and-thawing damage, and sulfate attack.

Numerous computer models exist that offer prediction of chloride ingress; rather than leaving software selection as an open issue, designers should identify specific software of their choosing and require it by specification. This is needed because the available software programs have vast differences in model capability, validation testing requirements, and cost. Performance tests are often incorrectly specified in design documents, and some tests may conflict with one another. For example, cracking is often neglected by software models. Unfortunately, development of highly corrosion-resistant concrete mixtures on the basis of uncracked paste properties can lead to autogenous shrinkage and early cracking susceptibility. Care should be taken to select the proper test for the desired performance and remember to address cracking as well, because cracks will short-circuit the service life of a well-designed concrete mixture. Ultimately, the owner and design engineer need to do their homework and be realistic with performance goals and criteria.

Second, the project team needs to ensure that the specification was developed properly with respect to practical issues and implementation. Are the necessary materials available in the local market? Are the local labs equipped to perform the necessary testing? Are the contractors aware of the need to address new requirements in their bids? One effective way to accomplish this is to involve all relevant stakeholders from an early stage in the specification development. Contractors, materials suppliers, and testing labs should be given the opportunity to evaluate and comment on specifications during the development. This will help lead to harmony once the specification is implemented. A recent example of this approach is the Illinois Tollway Authority's implementation of a new high-performance concrete bridge deck specification.13

Finally, the implementation of an effective performance specification must include realistic and efficient quality control testing. Overly complex and logistically challenging performance testing will discourage project team members and lead to conflicts or litigation. Whenever possible, preliminary qualification testing should be performed as early as possible and should include surrogate tests that have been validated in the laboratory for a particular mixture. For example, electrical resistivity measurements are often used as a surrogate to diffusion-based transport properties. However, a common mistake is forgetting to perform an initial qualification of the electrical test technique. Electrical properties vary with constituent materials; therefore, a correlation test is always needed (in accordance with ASTM C1202) to a ponding or immersion (true diffusion) based test method. This relationship cannot be assumed without prior test data for correlation. It is also desirable to set forth a resolution protocol for instances in which the quality control performance requirements are not met. Retesting, coring the structure, and application of a coating if retests are not satisfactory, are possible courses of action.

As producers gain experience with performance-based specifications, the challenges posed by acceptance testing may become less imposing. A producer may be able to offer several "off the shelf" mixture options for durability performance that are backed by prior test history. A similar framework is already in place for specification and acceptance for flexural strength properties for pavement concrete. This will not eliminate the need for acceptance testing for each project, but could potentially reduce the extent of acceptance testing required, thereby making performance specifications for durability feasible even for smaller projects.

Framework for Performance-Based "Alternatives" for Specifying Durability

Many of the current specifications and codes (for example, state and local DOTs specifications or ACI 318) are based on empirical observations that relate to aspects of mixture design. For example, the potential for cyclic freezing-and-thawing damage is currently addressed through limits on total air content and w/cm requirements. While these empirical approaches are useful, there have been recent developments in the area of performance specifications.14 Figure 2 illustrates a general approach that can be used to develop performance specifications by relating measured test results (Step 1) to material properties (Step 2). These material properties can then be used in predictive equations to estimate the service life or performance of concrete elements (Step 3). The estimated service life can then be related to performance grades in the specification (Step 4). This approach is powerful in that it allows variations in properties obtained in service to be related to performance based criteria (for example, time in service or cracking potential). Figure 2 also illustrates specific approaches that could be implemented to optimize performance of concrete subject to chloride exposure, cyclic freezing and thawing, or cracking due to restrained shrinkage. The following section provides a brief overview of the approaches used to predict the time to reach limit states associated with corrosion15 and cyclic freezing and thawing.16,17 Information regarding cracking due to restrained shrinkage can be found in the literature.18

In transport-related forms of degradation such as reinforcing steel corrosion, the penetration of an aggressive species like a chloride ion can be related to a material property that describes the pore structure and connectivity, such as the formation factor. The formation factor, or F Factor, can be related to both a diffusion coefficient19 and rapid field tests such as electrical resistivity. Reference 14 provides a case study for a bridge deck in Indiana. A sealed 91-day F Factor of 2400 was related to an anticipated 50-year service life. Practical field measurements for use in quality control and material acceptance were related to the indicated F Factor and to a design resistivity on a sealed sample.

Similarly, a sorption-based performance approach has potential for the development of specifications for concrete mixtures that are resistant to cyclic freezing and thawing. Current prescriptive specifications for concrete impose empirically based limits on air content and w/cm.17 The sorption-based approach is based on the degree of saturation of concrete after a short exposure to water (with the gel and capillary pores in the matrix being water filled) and

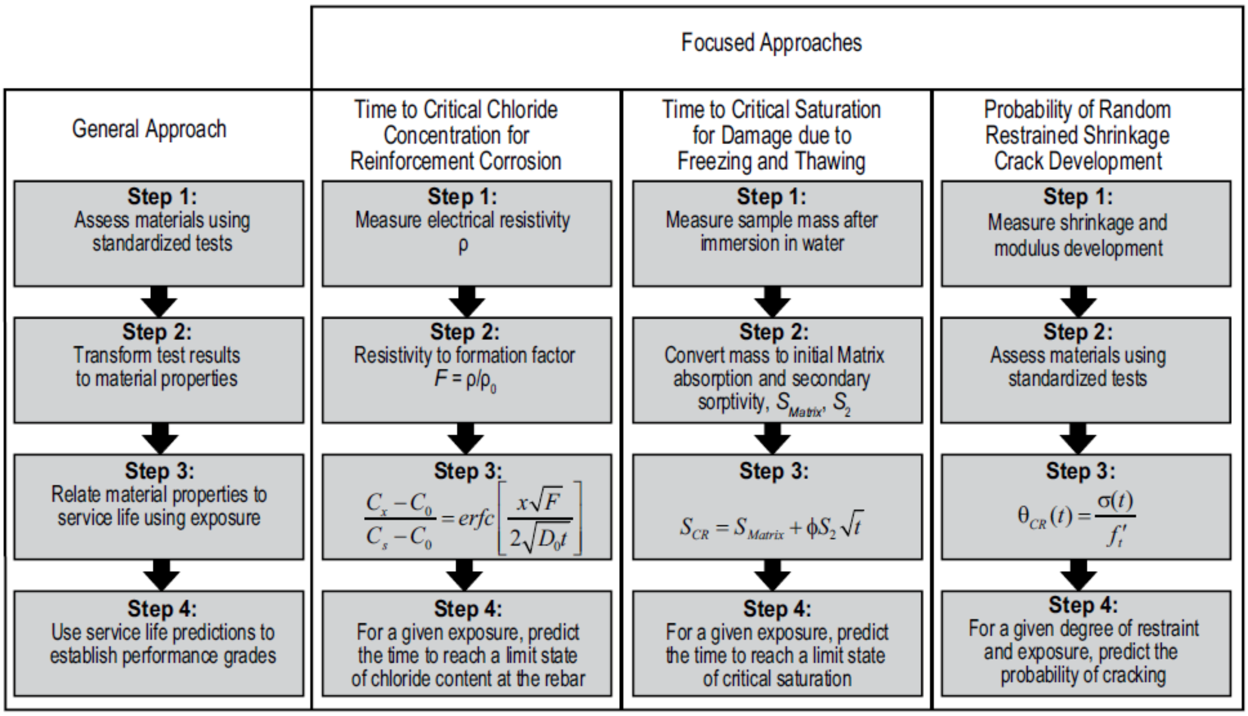


Fig. 2: Performance specifications can be developed by relating test results to material properties used in predictive equations

the rate of infilling of the air voids. While a variety of methods exists to ascertain these properties, recent research has shown that simple mass fresh air tests (for example, results of SAM tests) or mass measurements can be used for quality control and material acceptance testing. The performance-based approach could be useful to consider the role of topical treatments (sealers) or water-blocking admixtures.

The approach discussed in this section provides a potential alternative to empirically based prescriptive specifications. While there is no doubt that additional research is needed for the concrete community to become familiar with such approaches, it is important to note that the described approach relates acceptance test results to material properties and anticipated performance. This can be quite powerful in enabling innovations in mixture design, increased use of rapid sensing for quality control and acceptance, and improved strategies for managing the life-cycle of concrete infrastructure elements.

Summary and Looking Forward

The general consensus of the panel was that performance-based specifications have great potential as an alternative to prescriptive specifications. While it is fully expected that prescriptive specifications will remain necessary, performance specifications can provide an alternative that can lead to innovation, potentially more sustainable mixtures, improved concrete quality, and concrete mixtures optimized to meet performance requirements. Opportunities exist for improved laboratory tests that can be used for rapid assessment as well as for predicting long-term field performance. In addition, innovative methods are emerging for implementing rapid and reliable tests for measurement of transport properties. Advances in experimental methods20,21 and transport modelling are also likely yield software models that are able to better account for the effects of cracking on chloride ingress.22,23 Yet, the complexity of specifications, acceptance testing, and modeling will need to take into account project size and durability performance needs. For these reasons, performance specifications are suggested as an alternative to prescriptive specifications, rather than a complete replacement.

References

1. ACI Committee 301, “Specifications for Structural Concrete (ACI 301- 16),” American Concrete Institute, Farmington Hills, MI, 2016, 64 pp.
2. ACI Committee 318, “Building Code Requirements for Structural Concrete (ACI 318-14) and Commentary (ACI 318R-14),” American Concrete Institute, Farmington Hills, MI, 2014, 519 pp.
3. ACI Committee 201, “Guide to Durable Concrete (201.2R-16),” American Concrete Institute, Farmington Hills, MI, 2016, 82 pp.
4. “Moving Ahead for Progress in the 21st Century Act (MAP-21),” Federal Motor Carrier Safety Administration, U.S. Department of Trans-portation, Washington, DC, www.fmcsa.dot.gov/mission/policy/map- 21-moving-ahead-progress-21st-century-act.
5. “Fixing America’s Surface Transportation or ‘FAST Act’,” Federal Highway Administration, U.S. Department of Transportation, Washington, DC, www.fhwa.dot.gov/fastact/.
6. Ehlen, M.A.; Thomas, M.D.A.; and Bentz, E.C., “Life-365 Service Life Prediction Model™ Version 2.0,” Concrete International, V. 31, No. 5, May 2009, pp. 41-46.
7. Henchi, K.; Samson, E.; Chapdelaine, F; and Marchand, J.,“Advanced Finite-Element Predictive Model for the Service Life Prediction of Concrete Infrastructures in Support of Asset Management and Decision-Making,” Computing in Civil Engineering, L. Sobelman and B. Akinci, eds., American Society of Civil Engineers, Reston, VA, 2007, pp. 870-880.

8. Obla, K.H., and Lobo, C.L., "Prescriptive Specifications," Concrete International, V. 37, No. 8, Aug. 2015, pp. 29-31.
9. Obla, K.H.; Lobo, C.L.; and Kim, H., "The 2012 NRMCA Supplementary Cementitious Materials Use Survey," Concrete InFocus, NRMCA, Fall 2012, pp. 16-18.
10. Obla, K.; Lobo, C.; Hong, R.; and Kim, H., "Optimizing Concrete Mixtures for Performance and Sustainability," NRMCA, 2015, 52 pp., www.nrmca.org/research_engineering/Documents/OptimizingConcreteMixturesFinalReport.pdf.
11. ACI Committee 329, "Report on Performance-Based Requirements for Concrete (ACI 329R-14)," American Concrete Institute, Farmington Hills, MI, 2014, 46 pp.
12. ACI Committee 211, "Guide for Submittal of Concrete Propor-tions (ACI 211.5R-14)," American Concrete Institute, Farmington Hills, MI, 2014, 14 pp.
13. D'Ambrosia, M.D.; Slater, J.; and Dam, T.V., "High-Performance Concrete for Bridge Decks," Report for the Illinois State Toll Highways Authority, CTLGroup, Skokie, IL, 2013, 34 pp.
14. Graveen, C.; Falker, E.; Beaver, M.; Neithalath, N.; Weiss, W.J.; Olek, J.O.; Nantung, T.; and Gallivan, V.L., "Performance-Related Specification (PRS) for Concrete Pavements in Indiana," FHWA/IN/JTRP-2004/13, Indiana Department of Transportation, Indianapolis, IN, 2009, 422 pp.
15. Weiss, W.J.; Barrett, T.J.; Qiao, C.; and Todak, H., "Toward a Specification for Transport Properties of Concrete Based on the Formation Factor of a Sealed Specimen," Transportation Research Board, Washington, DC, 2016, 16 pp.
16. Li, W.; Pour-Ghaz, M.; Castro, J.; and Weiss, W.J., "Water Absorption and the Critical Degree of Saturation as it Relates to Freeze-Thaw Damage in Concrete Pavement Joints," Journal of Materials in Civil Engineering, ASCE, V. 24, No. 3, Mar. 2012, pp. 299-307.
17. Weiss, W.J.; Chang, M.T.; and Todak, H., "Is the Concrete Profession Ready for Performance Specifications that Provide an Alternative to Prescriptive w/c and Air Content Requirements?," 2016 International Concrete Sustainability Conference, NRMCA, June 2016, www.nrmcaevents.org/?nav=display&file=933.
18. Radlinska, A.; Rajabipour, F.; Bucher, B.; Henkensiefken, R.; Sant, G.; and Weiss, W.J., "Shrinkage Mitigation Strategies in Cementi-tious Systems: A Closer Look at Differences in Sealed and Unsealed Behavior," Transportation Research Record, V. 2070, 2008, pp. 59-67.
19. Weiss, W.J.; Ley, M.T.; Isgor, O.B.; and Van Dam, T., "Toward Performance Specifications for Concrete Durability: Using the Formation Factor for Corrosion and Critical Saturation for Freeze-Thaw," Annual Meeting Compendium of Papers, Transportation Research Board, Washington, DC, 2017. 20. Yoon, S.; Wang, K.; Weiss, W.J.; and Shah, S.P., "The Interaction between Loading, Corrosion, and Serviceability of Reinforced Concrete," ACI Materials Journal, V. 97, No. 6, Nov.-Dec. 2000, pp. 637-644.
20. Pease, B.J.; Geiker, M.; Stang, H.; and Weiss, W.J., "The Design of an Instrumented Rebar for Assessment of Corrosion in Cracked Reinforced Concrete," Materials and Structures, V. 44, No. 7, Aug. 2011, pp. 1259-1271.
21. Bentz, D.P.; Garboczi, E.J.; Lu, Y.; Martys, N.; Sakulich, A.R.; and Weiss, W.J., "Modeling of the Influence of Transverse Cracking on Chloride Penetration into Concrete," Cement and Concrete Composites, V. 38, Apr. 2013, pp. 65-74.

Additional information on the ASTM and AASHTO standards discussed in this article is available at www.astm.org and www.transportation.org, respectively.

Received and reviewed under Institute publication policies.

Tom Yu is Senior Pavement Design Engineer in the Office of Infrastructure at FHWA, Washington, DC. He is a member of ACI Committee 325, Concrete Pavements. He received his MS in civil engineering from University of Illinois at Urbana-Champaign, Champaign, IL, in 1984.

Casimir J. Bognacki, FACI, is the Chief of Materials Engineering at PANYNJ, New York, NY. He has over 30 years of experience in construction materials. His responsibilities include managing the inspection and testing services for all construction materials, investigating and incorporating the latest in materials technology into construction and maintenance work at Port Authority facilities. He serves on several ACI committees including ACI Committee 211, Proportioning Concrete Mixtures.

Karthik H. Obla, FACI, is Vice President of Technical Services at NRMCA, Silver Spring, MD. He serves on several ACI committees including ACI Committee 329, Performance Criteria for Ready Mixed Concrete. He is a winner of ACI's Young Professional Achievement Award and served as President of the San Antonio Chapter – ACI. He received his BS in civil engineering from IIT (BHU), Varanasi, India, and his MS and PhD in civil engineering from the University of Michigan, Ann Arbor, MI.

James K. Hicks is President of J.K. Hicks Engineering, Montgomery, TX, with over 40 years of experience in concrete and cement-based materials engineering. He is a member of several ACI committees including ACI Committee 329, Performance Criteria for Ready Mixed Concrete. He is the champion of the SDC Accelerated Technology Implementation Team on Alternative Cementitious Materials.

Matthew D. D'Ambrosia is a Principal Engineer at CTLGroup, Skokie, IL. He is a member of several ACI committees includ-ing ACI Committee 329, Performance Criteria for Ready Mixed Concrete; and 236, Materials Science of Concrete. He received his BS from the University of Iowa, Iowa City, IA, and his MS and PhD in civil engineering from the University of Illinois at Urbana-Champaign, Champaign, IL.

W. Jason Weiss, FACI, is the Edwards Professor of Engineering and Head of the School of Civil and Construction Engineering at Oregon State University, Corvallis, OR. He is Chair of ACI Committee 231, Properties of Concrete at Early Ages, and a member of several other ACI committees including ACI Committee 318, Structural Concrete Building Code. His research interests include fluid transport in concrete and service-life modeling.

Tengfei Fu is a post-doctoral researcher at Oregon State University. He received his PhD in 2013 with a focus on drying shrinkage and cracking on high-perfor-mance concrete for bridge decks. He is a member of several ACI committees including ACI Committee 123, Research and Current Developments. He was a recipient of the Portland Cement Association Education Foundation Fellowship in 2011.

Eric R. Giannini is an Assistant Professor in the Department of Civil, Construction and Environmental Engineering at The University of Alabama, Tuscaloosa, AL. He is a member of several ACI committees including ACI Committee 123, Research and Current Developments. His research interests include alkali-silica reaction and nondestructive testing. He received his PhD in civil engineering from The University of Texas at Austin, Austin, TX, in 2012.

MEMBERSHIP

WE ARE A
CARING
ASSOCIATION

Benefits of Joining Us?

Benefit #1
Access to the ACI Membership Directory

Benefit #2
Digital subscription to Concrete International Magazine

Benefit #3
Three ACI University tokens

Benefit #4
Printable ACI Membership Certificate

We believe a long lasting business relationship is built on friendship.

About Us

America Concrete Institute-Malaysia Chapter (ACI-Malaysia) is a non-profit technical and educational society representing ACI Global in Malaysia, which is one of the world's leading authority in concrete technology.
Our membership is not only limited to engineers, in fact it includes educators, architects, consultants, corporate bodies, contractors, suppliers and experts in cement and concrete related fields.

Contact Us

www.acimalaysia.org

70-1, Jalan PJS 5/30,
Petaling Jaya Commercial City (PJCC)
46150 Selangor, Malaysia.

+60 (3) 7782 2996 (Admin-1)
+60 (14) 2207 138 (Admin-2)

Email: info@acimalaysia.org

REGISTER NOW

WHY CHOOSE US?

We look forward to your kind support and, more importantly, to your participation and registration as a member of ACI-Malaysia Chapter. It is our firm belief your involvement and together with your commitments will go a long way in our quest to uphold all our objectives to mutually benefits for all members.

Open for Registration

JOIN US

+6014 220 7138 ☎
http://www.acimalaysia.org 🌐
admin@acimalaysia.org ✉

American Concrete Institute - Malaysia Chapter
70-1, Jalan PJS 5/30,
Petaling Jaya Commercial City (PJCC),
46150 Petaling Jaya, Malaysia.

American Concrete Institute – Malaysia Chapter
70-1, Jalan PJS 5/30, Petaling Jaya Commercial City (PJCC),
46150 Petaling Jaya, Selangor. Malaysia.
Tel.: **+60 (3) 7782 2996** Fax.: **+60 (3) 7782 1196**
Website: **www.acimalaysia.org** eMail: **info@acimalaysia.org**

Membership Application Form

Type of Membership (please tick "☑" one option only)

	Joining Fees (Total)(RM)	(Entrance Fee +	Subscription Fee per annum)
☐ Organizational Member:	A Firm, Corporation, Society, Government Agency or other organizations. **RM800.00**	(RM500.00 +	RM300.00)
☐ Associate Member:	An individual who is not a member of **ACI International** but American Concrete Institute – Malaysia Chapter only. **RM200.00**	(RM100.00 +	RM100.00)
☐ Student Member:	**RM30.00**	(RM30.00 +	RM0.00)

To be admitted as a **Chapter Member**(*), return this form together with **Crossed-cheque** (any outstation cheque to include Bank Commission)/ **Online Bank Transfer/ Cash Deposit** made payable to:

Account Holder Name: **American Concrete Institute – Malaysia Chapter**
Bank: **Hong Leong Bank Berhad (HLB)**
Account Number: **291.0002.0936**

*Once payment has been made, it is important to send **Remittance Slip/ Deposit Advice/ Bank Transfer Receipt** to our Administrative Office for confirmation, via these channels:*

WhatsApp: **+60 (14) 2207.138** (*ACI.my Administrative-2*); or
eMail: **admin@acimalaysia.org**

(*) Benefits provided by **ACI International** for Chapter Members:

1. Digital subscription to Concrete International magazine;
2. Access to the ACI Membership Directory; and
3. 3-Tokens to ACI University Courses;
4. Printable ACI Membership Certificate

Important Notes:

- Benefits will be accessible via Temporary Password sent to your email account either in the month of **June** or **December**, depend on time slot of **Chapter Member List** update to **ACI International**;
- All benefits are subject to change without prior notice.

Personal Particulars:

Are you a Member of **American Concrete Institute International** (ACI International)?
☐ No.
☐ Yes. (Please provide your ACI Int'l Membership Number: ______ Since (Year): ______)

Name: ______ (First) ______ (Last)
Salutation / Title: ______ (Mr./ Ms./ Mdm./ Ir./ Ar./ Dr./ Prof./) Other: ______
NRIC/ Passport No: ______ Nationality: ______
Mobile Number: +60 (1) - ______ Email: ______
Company / Organization: ______ Designation: ______
Postal Address: ______
______
Postal code: ______ State: ______
Tel.: ______ Fax: ______ Email: ______
I am introduced to ACI-Malaysia Chapter by: ______

Applicant Signature ______ Date ______

For Office Use Only

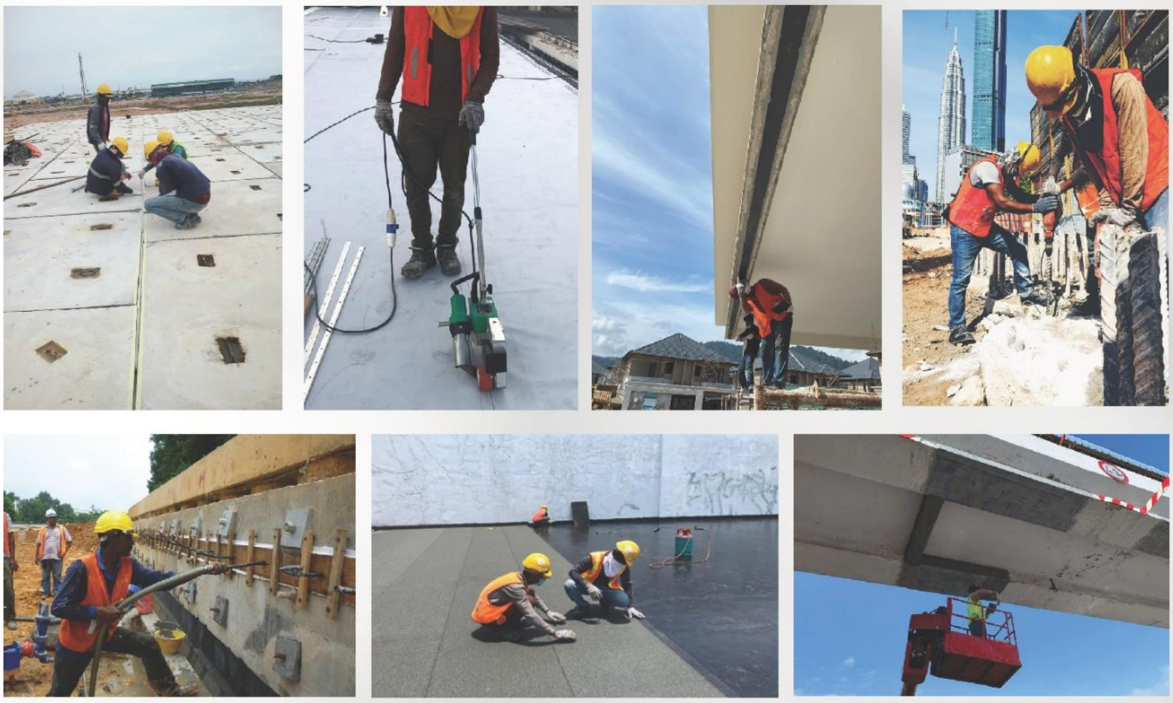
Membership No: ☐☐ - ☐☐☐☐ Receipt No.: ______ Date: ______
Verified by: ______ (Name: ______) Date: ______

☐ **NF/ RF** ☐ **PoP** ☐ **DB** ☐ **MRR** ☐ **GglC** ☐ **RvnT** ☐ **InvT** ☐ **I&R** ☐ **MF/PoP/I&R-F**

PREMIUM SPONSORSHIP

JKS REPAIRS SDN. BHD.

STRUCTURAL REPAIRS AND REHABILITATION SERVICES



- Concrete Repair
- Protective Coating
- Structural Strengthening
- Waterproofing
- Resin Injection System
- Concrete Joint Sealing
- Structural Anchoring
- Control Demolition
- Firestop & Protection System
- Structural Integrity Assessment

Contact us
for inquiries
+6017 234 7070

JKS REPAIRS SDN. BHD.
No. 21, Jalan Utarid U5/23,
Bandar Pinggiran Sebang,
40150 Shah Alam,
Selangor Darul Ehsan
Tel: +6017 234 7070
email : jks.repairs@gmail.com
Website : www.jksrepairssb.com

LOYAL SPONSORSHIP

Space available for sponsorship
Please contact: +6014 220 7138

Space available for sponsorship
Please contact: +6014 220 7138

NOTES

American Concrete Institute - Malaysia Chapter
70-1, Jalan PJS 5/30, Petaling Jaya Commercial City (PJCC),
46150 Petaling Jaya, Malaysia.