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American Concrete Institute
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THE BULLETIN OF THE AMERICAN CONCRETE INSTITUTE - MALAYSIA CHAPTER
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MyConcrete:
The Bulletin of the American Concrete Institute – Malaysia Chapter

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AMERICAN CONCRETE INSTITUTE-MALAYSIA CHAPTER

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5.00 PM - AGM
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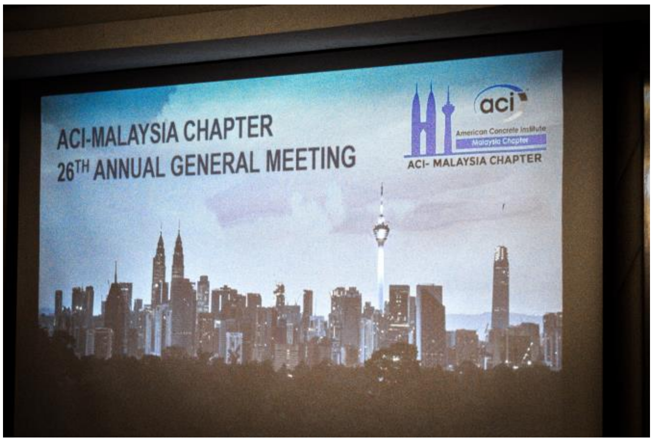
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ARTICLE

Partial Replacement of Cement with Silica Extracted from Agricultural Waste: Effect of Pre-Treatment with Low-Concentration Acid on Early Compressive Strength of Concrete.

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Abstract: In view of the high level of carbon dioxide emission that arises from the production of cement, adoption of supplementary cementitious materials (SCM) as partial replacement of cement in concrete has been explored in previous research. Agricultural wastes, such as rice husk ash (RHA) and sugarcane bagasse ash (SCBA), can be adopted as SCMs as they are abundant in many parts of the world and rich in silica. Prior to burning the waste, pre-treatments using acids have been performed in previous studies to eliminate metal impurities in order to increase the content of silica that can be extracted. However, chemical hazards that arise from utilization of the acids at high concentrations are a deterrent to the implementation of pre-treatment as part of an eco-friendly process of adopting agricultural wastes as SCMs. In view of the chemical hazards, the present study investigates the effect of performing pre-treatments on rice husk and sugarcane bagasse with a low concentration acid of 0.1 M on the early compressive strength of concrete. Partial replacement of cement in the concrete was performed using silica ex-tracted from RHA and SCBA as the SCMs. Results show that pre-treatment of agricultural waste is necessary in order to produce concrete that possesses sufficient compressive strength that is comparable with that of conventional concrete. Partial replacement of cement with silica extracted from pre-treated RHA resulted in the highest com-pressive strength of 6.44 MPa, which is an increase of 8.50% from that of the conventional concrete, while that from pre-treated SCBA resulted in an increase of 5.37%.

Keywords: agro-waste; rice husk ash; sugarcane bagasse ash; ordinary Portland cement; supplementary cementitious materials.

Introduction

Ubiquitous application of concrete in construction industries worldwide is attributable to the accessibility of raw constituent materials, favorable strength and durability, flexibility in application and low cost of repair [1–3]. It has been reported that quantity of cement produced yearly has increased by an average of 2.5% after each year, which is from 2.3 Gt to 3.5 Gt from 2005 to 2020. The quantity has been projected to further increase to 4.4 Gt by 2050 [1,4].

About 110 kWh of electrical energy is consumed for firing of about 1.6 tons of raw materials in a kiln for production of 1 ton of ordinary Portland cement [5–7]. Moreover, about 0.7–1 ton of carbon dioxide is generated from the production of cement owing to consumption of fuel to burn and grind the raw materials as well as decomposition of limestone and chalk to be utilized as the raw materials. It is well-known that emission of the carbon dioxide increases the greenhouse effect and contributes to global warming. About 6–8% of anthropogenic carbon dioxide emission is contributed by the production of cement [8–12].

In view of the high level of carbon dioxide emission that arises from the production of cement, adoption of supplementary cementitious materials (SCM) as partial replacement of cement in concrete has been explored in previous research. The adoption of SCM can reduce carbon dioxide emission by up to 30–40% [11–13]. It can also lead to reduction in cost as well as improvement in several properties of concrete as it contains additional reactive silica that facilitates the formation of cementitious compounds of calcium–silicate–hydrate [14]. Industrial wastes, such as fly ash from the combustion of coal and granulated blast furnace slag from the production of steel, are the most prevalent SCMs [11, 15–18].

Apart from industrial wastes, agricultural wastes can also be adopted as SCMs as they are abundant in many parts of the world and rich in silica [19]. As the wastes are immensely abundant worldwide, their disposal by means of dumping in landfills as well as open and uncontrolled burning, which are associ-ated with various harmful effects to the environment. Rice husk and sugarcane bagasse ashes are, among others, widely studied as SCMs [20].

Prior to burning of the waste, pre-treatments using acids have been performed in previous studies [21–23] to eliminate metal impurities, such as calcium, magnesium and potassium, in order to increase the con-tent of silica that can be extracted. Concentrations adopted for the acids range from 1 M to 6 M. However, chemical hazards that arise from utilization of the acids at high concentrations are a deterrent to the implementation of pre treatment as part of an eco-friendly process of adopting agricultural wastes as SCMs. In view of the chemical hazards, the present study investigates the effect of performing pre-treatments on rice husk and sugarcane bagasse with a low-concentration acid of 0.1 M on the early compressive strength of concrete. Partial replacement of cement in the concrete was performed using silica extracted from rice husk ash (RHA) and sugarcane bagasse ash (SCBA) as the SCMs.

Materials and Methods

Rice husk and sugarcane bagasse were obtained from a local supplier in Perak, Malaysia. They were rinsed with water to remove dirt and contaminants. Pre-treatment was then performed by soaking them in a low-concentration acid, which is 0.1 M of hydrochloric acid (HCl), for an hour. After soaking, they were drained, rinsed with deionized water and left to dry under the sun. Raw and pre-treated rice husk and sugarcane bagasse were burned in a muffle furnace at 600°C for an hour to produce untreated and pre-treated RHA and SCBA, respectively.

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X-ray diffraction (XRD) and X-ray fluorescence (XRF) analyses were conducted to perform material characterization of the RHA and SCBA. The XRD analysis was conducted using an X-ray diffractometer. The XRF analysis was conducted using an XRF spectrometer.

Extraction of silica gel was performed on the RHA and SCBA. The RHA and SCBA were mixed with sodium hydroxide (NaOH) separately. The mixture was placed on a hot plate at 100°C for one hour and then left to cool to room temperature. After cooling, the mixture was filtered. The filtrate, which is sodium silicate (Na_2SiO_3), was precipitated with 1 mol/L of HCl solution until a neutral pH was reached. The solution was left at room temperature for 24 hours to form the silica gel. Then, the gel was dried in an oven at 150°C for four hours to convert it into a powder. The powder was incorporated into concrete mixtures for preparation of samples that adopt partial cement replacement.

Three types of concrete samples were prepared. Mix proportions for all sample types, which are the control sample that does not contain any SCM and samples that contain 5% silica from untreated and pre-treated RHA and SCBA as the SCM, are displayed in Table 1. The silica was added during mixing of the concrete. The mixtures were poured into molds with dimensions of 50 mm × 50 mm × 50 mm to pre-pare cube samples. The samples were cast for 24 hours before they were removed from the molds and cured in water. Compressive strength tests were performed on the samples after seven days of curing using a digital compressive testing machine in accordance with the standard BS EN 12390–3 [24].

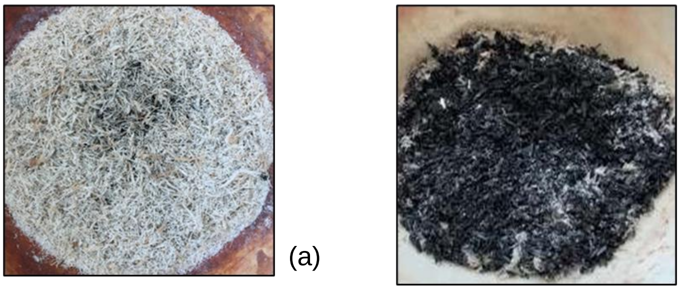
Sample	Cement (g)	Sand (g)	Water (g)	Silica (g)
Control	87.50	371	84	0
Contains 5% silica from un-treated RHA	83.14	371	84	4.38 (untreated)
Contains 5% silica from pre-treated RHA	83.14	371	84	4.38 (pre-treated)
Contains 5% silica from un-treated SCBA	83.2	371	84	4.38 (untreated)
Contains 5% silica from pre-treated SCBA	83.2	371	84	4.38 (pre-treated)

Results and Discussion

Burning of Sugarcane Bagasse and Rice Husk

Figures 1 (a) and 1 (b) display the appearance of the pre-treated RHA and SCBA at the burning temperature of 600°C, respectively. The color of RHA produced was white, which indicates that the burning process achieved a complete combustion with the presence of less impurities [25] while the SCBA produced was black due to the presence of unburned carbon [26].

Figure 1. Appearance of pre-treated
(a) rice husk ash (RHA) and
(b) (b) sugarcane bagasse ash (SCBA) at the burning temperature of 600°C


(a) (b)

X-Ray Diffraction Analysis

XRD analysis was conducted on the pre-treated RHA and SCBA to determine their crystallographic structure. Figures 2 (a) and 2 (b) reveal XRD patterns for the pre-treated RHA and SCBA at the burning temperature of 600°C, respectively.

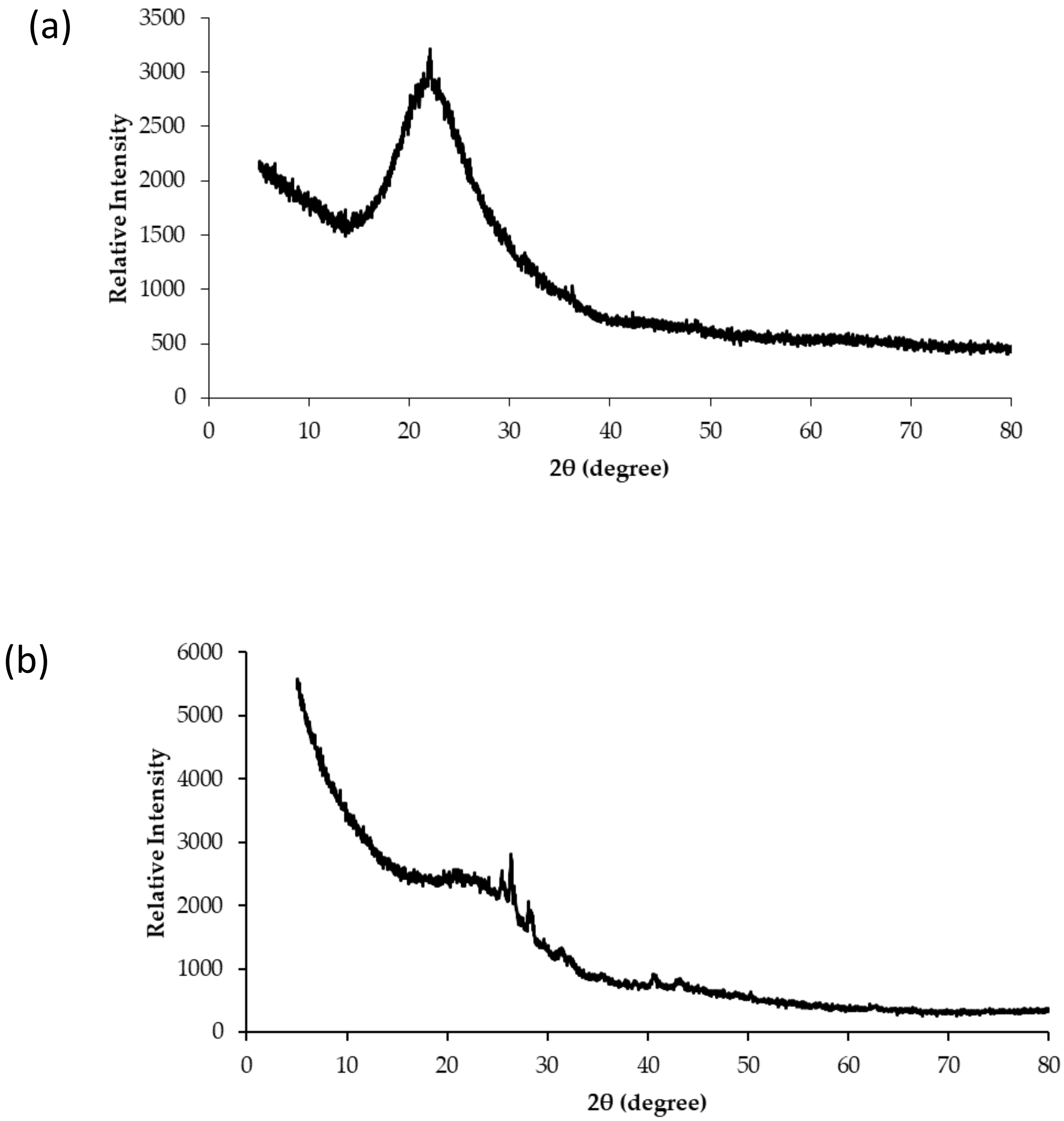


Figure 2. X-ray diffraction patterns for pre-treated (a) RHA and (b) SCBA at the burning temperature of 600°C

The patterns in Figure 2 reveal that the RHA and SCBA are amorphous. Figures 2 (a) and 2 (b) reveal that the diffraction angle peaks of the RHA and SCBA are between 2θ = 5° and 2θ = 80°, which is in agreement with Hasnain et al. [27] that discovered that common diffraction angle peaks for RHA and SCBA are be-tween 2θ = 5° and 2θ = 80°. The diffraction peaks of both RHA and SCBA was at 2θ = 22° and 2θ = 27°, respectively.

X-Ray Fluorescence Analysis

XRF analysis was performed to identify chemical components of the pre-treated RHA and SCBA at the burning temperature of 600°C as it can be implied that, according to Bakar et al. [28], the temperature will result in the production of amorphous silica with a purity of above 99%. Table 2 reveals the chemical composition of the agricultural wastes obtained from the analysis. Silica dioxide (SiO2) content of the RHA is 91%, which is the highest among all chemical components, and is in agreement with the result of Daulay et al. [29], while that of the SCBA is 28.8%, which is comparable to that of other types of agricultural waste, such as palm oil fuel ash, where the SiO2 content ranges between 20 and 31% [30, 31].

Chemical Component	Mass [%]	
	RHA	SCBA
SiO_2	91.00	28.80
Fe_2O_3	1.49	9.79
P_2O_5	1.43	4.59
CaO	1.25	20.50
K_2O	1.12	10.70
SO_3	-	8.41
Cl	-	6.05
MgO	-	3.48
Al_2O_3	-	2.95
Cr_2O_3	-	1.54

Table 2. Chemical composition of the agricultural wastes

Extraction of Silica Gel

Extraction of silica gel from the agricultural wastes were performed. The gel was then converted into a powder. Table 3 reveals images of the powder obtained from the untreated and pre-treated agricultural wastes. At the burning temperature of 600°C, the color of the powder formed from RHA was yellow while that formed from SCBA was white.

Table 3. Appearance of silica powder extracted from untreated and pre-treated rice husk ash (RHA) and sugar-cane bagasse ash (SCBA).

	Untreated	Pre-Treated
RHA		
SCBA		

Compressive Strength Test

Compressive strength tests were performed on control samples and samples containing 5% silica extracted from untreated and pre-treated RHA and SCBA after seven days of curing. Compressive strengths were compared with those of control samples without partial replacement of cement. Compressive strength of the control sample was 5.96 MPa. As shown in Figure 3, partial replacement of cement with 5% silica from untreated RHA and SCBA resulted in decreases in compressive strength by 20.13 and 19.13% relative to the control sample, respectively. Compressive strengths of the concrete decreased from 5.96 MPa to 4.76 and 4.82 MPa as a result of the partial replacement of cement with 5% silica from un-treated RHA and SCBA, respectively.

Contrarily, as shown in Figure 4, partial replacement of cement with 5% silica from pre-treated RHA and SCBA resulted in increases in compressive strength by 8.5 and 5.37% relative to the control sample, respectively. Compressive strengths of the samples increased from 5.96 MPa to 6.44 and 6.28 MPa as a result of the partial replacement of cement with 5% silica from pre-treated RHA and SCBA.

Microstructure and properties of cement in the concrete are affected by the inclusion of silica. Silica has smaller particle sizes and higher rates of pozzolanic activity [32]. Results indicate that pre-treatment has to be performed on the agricultural wastes in order to produce concrete with partial replacement of cement that possesses sufficient compressive strength that is comparable with that of conventional concrete.Adding cementitious elements, such as silica extracted from RHA and SCBA, enhances the microstructure of the concrete and leads to the development of less permeable concrete. The mechanical and durability characteristics of concrete are significantly influenced by the interfacial transition zone, pore connectivity and pore structure [33].

Partial replacement of cement with silica from the pre-treated RHA contributes to a higher compressive strength than that of SCBA due to the higher SiO2 content in RHA than that in the pre-treated SCBA. Although the SiO2 content in the pre-treated SCBA is relatively low as compared with that in the pre-treated RHA, the presence of a wider variety of elements in the pre-treated SCBA could be the factor that contributed to the increase of compressive strength of the concrete.

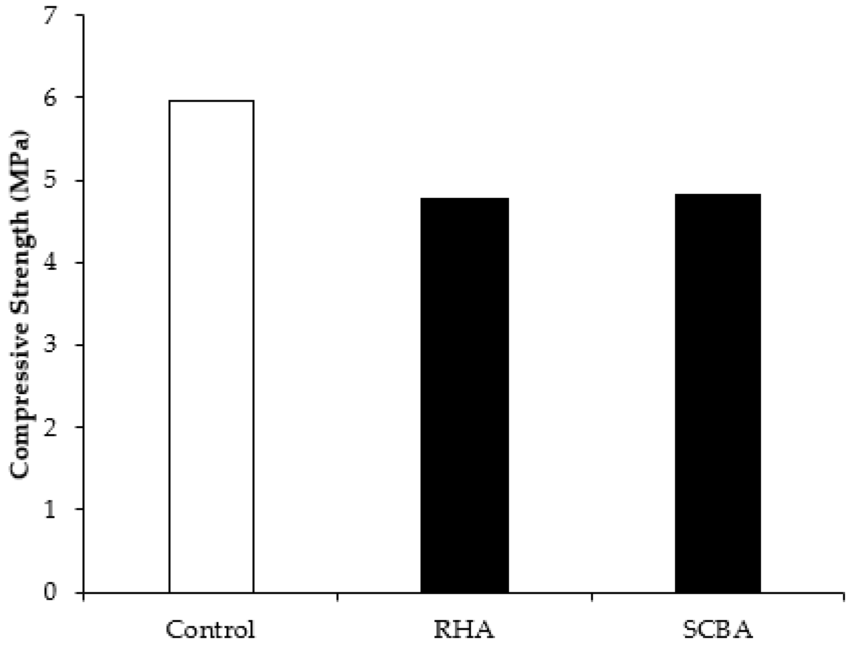


Figure 3. Compressive strength of control samples and samples containing 5% silica extracted from untreated RHA and SCBA

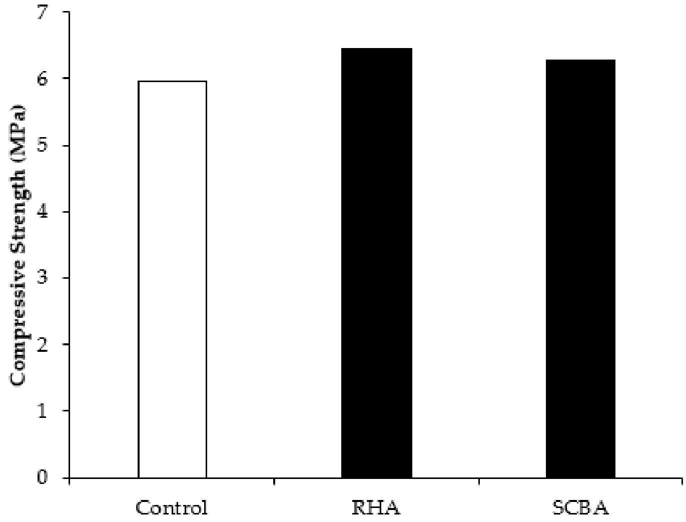


Figure 4. Compressive strength of control samples and samples containing 5% silica extracted from pre-treated RHA and SCBA.

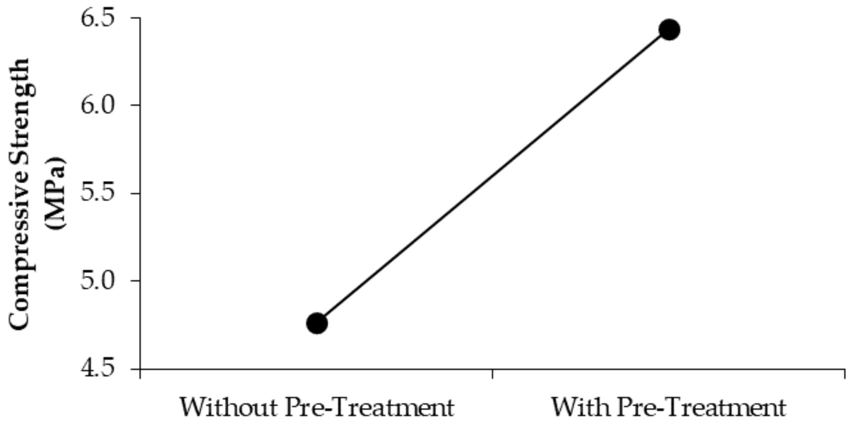


Figure 5. Compressive strength of samples containing 5% silica extracted from RHA without and with pre-treatment.

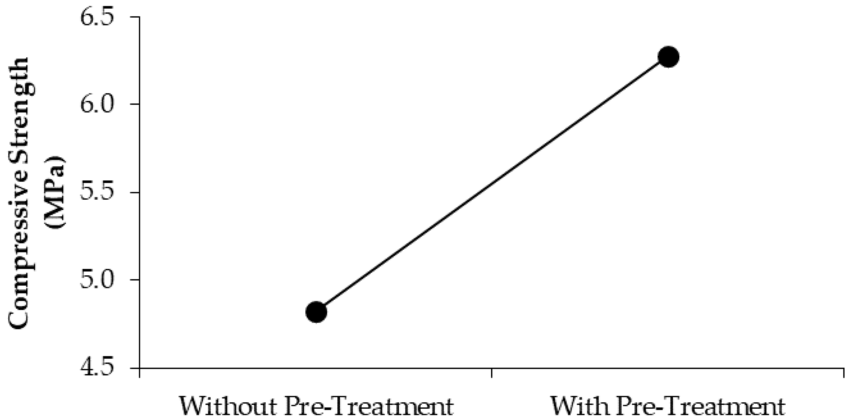


Figure 6. Compressive strength of samples containing 5% silica from SCBA without and with pre treatment.

Conclusion and Recommendations

The present study investigates the effect of performing pre-treatments on rice husk and sugarcane bagasse with a low concentration acid of 0.1 M on the early compressive strength of concrete. Partial replacement of cement in the concrete was performed using silica extracted from RHA and SCBA as the SCMs. Com-pressive strength tests as well as XRD and XRF analyses were performed on concrete samples to assess the effect of the pre treatments on the silica extraction. Results show that pre-treatment of agricultural waste is necessary in order to produce concrete that possesses sufficient compressive strength that is comparable with that of conventional concrete. Partial replacement of cement with silica extracted from pre-treated RHA resulted in the highest compressive strength of 6.44 MPa, which is an increase of 8.50% from that of the conventional concrete, while that from pre-treated SCBA resulted in an increase of 5.37%. Partial replacement of cement with silica from pre treated RHA contributes to a higher compressive strength than that of SCBA due to a higher SiO2 content in RHA.

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TECHNICAL REPORT

Reprint from CI Magazine, Volume 39, No 5, Page 48-52

Composite Strengthening of a Bridge

Claimed to be world's first field application of post-tensioned near-surface-mounted carbon fiber-reinforced polymer reinforcement.

by Woo-tai Jung, Moon-seoung Keum, Jong-sup Park, Jae-yoon Kang, Young-hwan Park, Wonseok Chung, and Yail J. Kim

Carbon fiber-reinforced polymer (CFRP) composites offer many benefits for bridge repair, including high strength and modulus, light weight, convenient and rapid implementation, corrosion resistance, minimal interruption to service, reduced labor for installation and maintenance, negligible relaxation under load, and favorable life-cycle costs.[1,2] Thus, CFRP composites have been widely employed for strengthening for over two decades. CFRP sheets and laminates may be externally bonded (EB) to a concrete substrate, or CFRP strips/rods can be near-surface-mounted (NSM) by inserting and adhesively bonding them into grooves precut into a concrete member. NSM systems have advantages over EB systems, including enhanced bond made possible by the increased contact area [3] and improved durability due to locating the repair material inside the concrete.

NSM CFRP composite repairs can also be post-tensioned. This allows the designer to better use the material's high strength and to upgrade the performance of existing members, in terms of both load-carrying capacity and serviceability (for instance, controlled deflections and crack initiation), to levels not achievable using conventional nonprestressed NSM CFRP applications. Several techniques have been tested for post-tensioning NSM CFRP, including prestressing beds, [4] rod anchors, [5] end-cap anchors,[6] and bracket anchors.[7] Also, a number of beam tests have been conducted in the laboratory to examine the load-carrying capacity, fatigue resistance, and ductility of post-tensioned NSM CFRP reinforcement. [8] Although external post-tensioned CFRP reinforcement (bonded and unbonded) has been used to retrofit/repair deficient bridges,[9,10] we are not aware of any field applications of post-tensioned NSM CFRP reinforcement.

In 2016, we used the post-tensioned NSM CFRP strengthening technique to upgrade one span of an existing bridge. The current article presents this proof-of-concept application, with an emphasis on post-tensioning procedures and equipment.

The Bridge

The Buhung Bridge, located in Gyeonggi, South Korea, was constructed in 1960. The four-span structure was designed for a live load of 32.4 tonnes (35.7 tons) (DB-18 in the Korean highway bridge design code11 [similar to the AASHTO HS20-44 loading in the U.S. bridge specification12]). The deck is 9.6 m (31.5 ft) wide and 50 m (164 ft) long, accommodates two traffic lanes, and is supported by reinforced concrete T-girders (Fig. 1). Each girder has 12 deformed steel bars totaling 3018 mm2 (4.67 in.2) in cross-sectional area. Concrete cover on the bars ranges from 50 to 58 mm (2.0 to 2.3 in.). Schmidt hammer tests revealed that the girder concrete had a compressive strength of about 30 MPa (4350 psi), 30% higher than the specified strength of 21 MPa (3050 psi).

Because there is a military base in the vicinity, the bridge was frequently overloaded by trucks and tanks. Accordingly, an upgrade was planned, with the goal to increase the capacity of the bridge to 43.2 tonnes (47.6 tons) (DB-24)—about a 30% improvement.

Strengthening Scheme

Figure 2 is a schematic for the strengthening method, showing the steps required to install the post-tensioned NSM CFRP rods. As an initial step, a narrow groove is cut along the length of the girder and wider recesses are created for anchorages (Fig. 2(a)). An anchor block is mounted in each recess using high-strength mechanical anchors, and the CFRP rod is installed (Fig. 2(b)). After positioning a jacking apparatus (Fig. 2(c)), a hydraulic ram is operated to apply the desired level of post-tensioning force to a steel anchorage sleeve bonded to the CFRP rod (Fig. 2(d)). The CFRP force is then

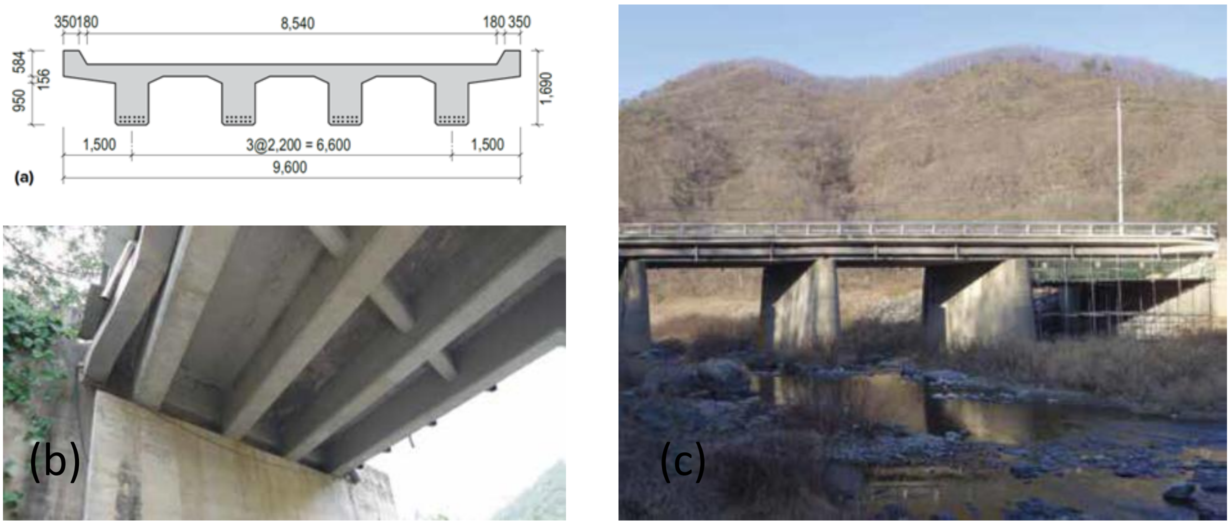

Fig. 1: The Buhung Bridge: (a) cross section, with dimensions in mm; (b) view of girders and abutment; and (c) overview, with scaffolding installed in test span (Note: 1 mm = 0.04 in.)

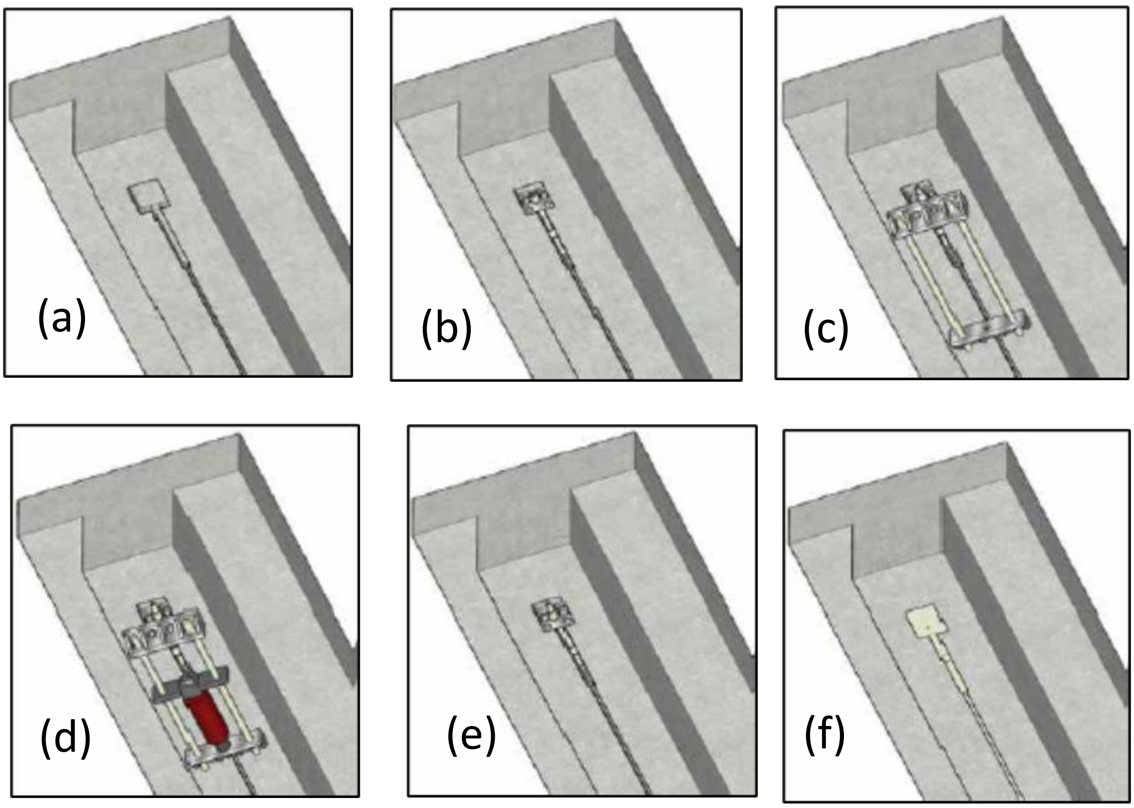

Fig. 2: Strengthening scheme: (a) groove and anchorage zone are cut into the girder; (b) anchorage and CFRP rod are installed; (c) jacking apparatus is mounted; (d) post-tensioning force is applied to anchorage sleeve on the CFRP rod; (e) force is transferred from the jacking apparatus to a fastening nut on the end of the anchorage sleeve; and (f) the groove and anchorage zones are grouted.

transferred from the jacking apparatus to a fastening nut on the end of the anchorage sleeve (Fig. 2(e))—the fastening nut is tightened against the anchor blocks, resulting in zero anchorage losses. To enhance the aesthetics of the strengthened girder and to improve the durability of the NSM CFRP system, the groove and anchorage recesses are grouted (Fig. 2(f)).

Site Implementation

To upgrade the Buhung Bridge, a post-tensioning force of 200 kN (45 kip) was required in each girder. We selected a commercially available CFRP rod coated with brown fused aluminum oxide for improved bond. The rod stock had a modulus of 178 GPa (25,800 ksi), a nominal tensile strength

Fig. 3: Preparation for NSM CFRP rod application: (a) each anchorage region was opened using chisels; and (b) grooves were cut using a saw mounted on a scissor lift guided by rails.

Fig. 4: Views of anchor blocks and rod anchorage sleeves: (a) a worker installs one of the four mechanical anchors used to mount an anchor block to the concrete girder; (b) installed anchor blocks; (c) anchor blocks with fixed-end anchor sleeves; and (d) anchor blocks with jacking-end anchor sleeves and fastening nuts

of 3500 MPa (508 ksi), and a cross-sectional area of 78.5 mm2 (0.12 in.2), so attaining the required force called for two CFRP rods per girder. Each CFRP rod had to be tensioned up to a force of 100 kN (22.5 kip)—about 42% of the nominal strength with an assumed long-term loss of 5%.

The first steps on site were installing scaffolding and chiseling of the NSM bar anchorage recesses (Fig. 3(a)) to secure a space of 250 mm (9.8 in.) long by 140 mm (5.5 in.) wide per anchor. Rails were then placed below the girder, and a trolley equipped with a portable saw-cut machine was rolled along the girder length to cut two grooves (30 mm [1.2 in.] wide and 40 mm [1.6 in.] deep) per girder (Fig. 3(b)).

Figure 4 illustrates the procedures required for anchorage and rod installation. After epoxy was applied to the concrete to improve the bearing of the block against the chiseled concrete, H-shaped galvanized steel anchor blocks (140 x 140 mm[5.5 x 5.5 in.]) were installed. The anchor blocks were mounted in the recesses using high-strength steel mechanical anchors (18 mm [0.7 in.] in diameter with a length of 105 mm [4.1 in.] each), as shown in Fig. 4(a) and (b). The mechanical anchor shanks were expansible by turning the hexagonal head with a torque wrench; therefore, a bonding agent inside the drilled hole was not necessary. To avoid structural damage, the anchors were positioned between the longitudinal reinforcing bars embedded in the girders. The CFRP rods were then threaded through the anchor blocks. The fixed-end anchorage sleeves are shown in Fig. 4(c), and the jacking-end anchorage sleeves (with fastening nuts) are shown in Fig. 4(d).

Upon completion of the anchorage installation, a jacking apparatus was positioned for post-tensioning the CFRP. The apparatus was composed of L-shape brackets, load-bearing rods with threads, a stability plate, and channels (Fig. 5). A load cell was used to monitor post-tensioning forces applied by a hydraulic ram (Fig. 6(a), (b), and (c)). The load cell reading was confirmed by measuring CFRP elongation (Fig. 6(d)). After achieving the planned post-tensioning force, the fastening nut was adjusted to permanently hold the force and allow removal of the jacking apparatus (Fig. 6(e)). After the four girders were strengthened using this procedure, the grooves and anchorage areas were filled with an epoxy grout (Fig. 7(a)), and the upgraded girders were repainted to look pristine (Fig. 7(b)).

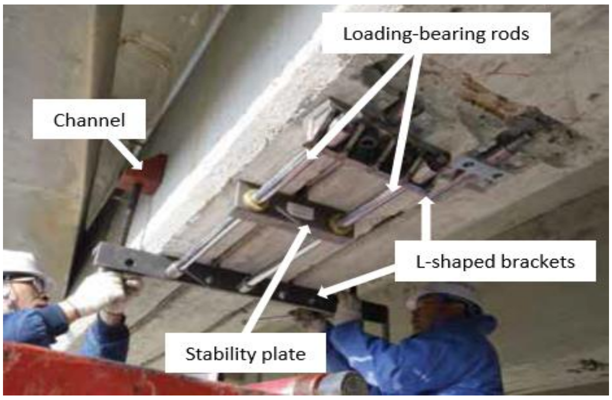

Fig. 5: Installation of the jacking apparatus. The stability plate includes a yoke that transfers the jacking force to the jacking-end anchorage sleeve on the CFRP rod

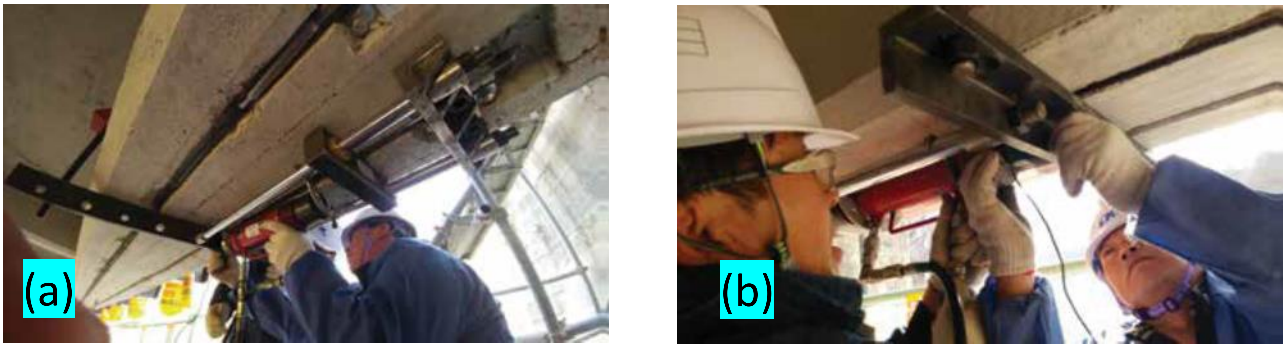

Fig. 6: Post-tensioning of NSM CFRP: (a) mounting of hydraulic ram in the jacking apparatus; (b) inserting a load cell between the ram and bracket; (c) completed jacking apparatus during operation; (d) measurement of elongation at jacking-end; and (e) fastening nut adjusted to lock-in post-tensioning force prior to removal of jacking apparatus.

Fig. 7: Appearance of upgraded girders: (a) after completion of epoxy grouting; and (b) after painting.

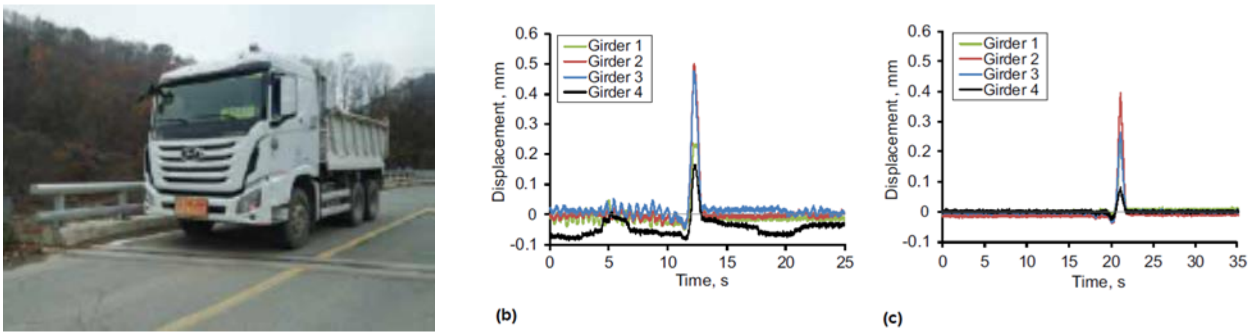

Fig. 8: Dynamic load tests were conducted by measuring midspan deflection as a 27 tonne (30 ton) truck moved over the bridge at 50 km/h (30 mph): (a) truck used in tests; (b) pre-strengthening test results; and (c) post-strengthening test results

Load Test

A 27 tonne (30 ton) truck (Fig. 8(a)) was used to conduct a dynamic load test and examine the behavior of the upgraded span. Deflections were monitored using four linear variable displacement transformers (LVDTs) positioned at midspan of the individual girders. With the track traversing the span at an operating speed of 50 km/h (30 mph), the maximum deflection of the strengthened girders decreased by 21% in comparison with their original counterparts (Fig. 8(b) and (c)). This observation indicates that the installed strengthening scheme was effective from serviceability perspectives, in addition to providing increased capacity.

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CASE STUDY

Reprint from CI Magazine, Volume 39, No 2, Page 54-55

Crumb Rubber Concrete Bridge Deck

Unique project in Tianjin, China, has performed well for over a decade.

by Han Zhu

Crumb rubber concrete (CRC) is a mixture of plain portland cement concrete with rubber crumbs, granular material produced by shredding and comminuting scrap automobile tires. Engineering research on CRC begun in the late 1980s and early 1990s. One of the early studies was carried out by Eldin and Senouci[1] who explored the effect of rubber chips and rubber crumbs on the compressive and tensile (flexural) strengths of concrete mixtures. After 30 years of research, CRC material properties have been extensively studied and are now well understood.[2]

In comparison with plain concrete, CRC has increased ductility, deformation capacity, energy absorption, damping capacity, and resistance to cyclic freezing and thawing as well as decreased water permeability, chloride ion permeability, and thermal expansion. These results have been repeatedly observed in laboratory experiments, and CRC's ability to resist cracking has been found to be exceptionally profound. One major drawback for CRC is a reduced compressive strength relative to plain concrete. But this reduction can be compensated by increasing the cement content or decreasing the water-cement ratio by using water reducers in the mixture.[3]

While CRC exhibits preferred material properties in many aspects, its durability has been one of the major concerns. Rubber is organic and other ingredients in concrete are inorganic, so how do those two materials get along as time goes by? Perhaps because of this concern, few reports can be found in the published literature about CRC applications in real-world projects.[4]

CRC Bridge Deck

In June 2006, the author led a team that worked with Tianjin municipality in China, to build a CRC bridge deck on Route S229 in the suburb of Wu-qing District (Fig. 1). The deck is 24 m (79 ft) long, 8 m (26 ft) wide, and 120 mm (5 in.) thick. The deck is reinforced at mid-depth with steel welded wire reinforcing with 10 mm (0.4 in.) wires on a 100 x 100 mm (4 x 4 in.) grid. The design 28-day compressive strength of the concrete was 40 MPa (5800 psi). The CRC mixture used for the bridge deck contained 480 kg/m3 (809 lb/yd3) cement, 100 kg/m3 (169 lb/yd3) fly ash, 60 kg/m3 (101 lb/yd3) sand, 1073 kg/m3 (1809 lb/yd3) gravel, 160 kg/m3 (270 lb/yd3) water, 92 kg/m3 (155 lb/yd3) rubber, and 5.8 kg/m3 (9.8 lb/yd3) high-range water-reducing admixture.

The construction was mainly carried out by a team of the author's graduate students. A small mobile mixer was used. The material components were not weighed, but were measured by volume using a bucket and then "fed" into the mixer. Therefore, the mixture proportions were followed only roughly. It was also raining on the day of construction, and that disrupted the concrete placement a number of times. So, generally speaking, the construction quality was poor. Curing, however, was done well—by creating small dams at both ends of the deck, it was possible to pond the deck for 1 week.

Fig. 2: Close-up look at the deck surface during inspection in June 2016, 10 years after placement

Compressive strength of the CRC exceeded the design strength and was 31.2 MPa (4530 psi) at 1 day, 37.5 MPa (5440 psi) at 7 days, and 42.1 MPa (6110 psi) at 28 days. Flexural strength was 6.9 MPa (1000 psi) at 28 days.

Rubber is as light as water and so a major concern is that vibrating fresh concrete may allow rubber crumbs in the mixture to float upward. One way to control this behavior is to design a concrete mixture with a low slump. For this CRC deck project, the measured slump was about 35 to 80 mm (1.5 to 3 in.), and no significant floating of the rubber crumbs was observed.

More technical details can be found in Reference 5. After the deck was opened for service in late August 2006, the traffic load has been low—about 400 daily passes of sedans or small trucks. The local weather is mild. Annual average temperature is about 13°C (55.4°F), and annual precipitation has been about 300 mm (12 in.) in recent years.

Inspection

The bridge deck has been inspected from time to time. The last inspection was completed in June, 2016. Overall, the deck looks good (Fig. 2). Shortly after placement, some early shallow shrinkage cracks were noted in an area limited to less than about 5% of the total deck surface. After 10 years, however, those shallow cracks have remained almost unchanged. The other 95% of the deck has remained crack-free, and the deck looks almost the same as the day it was opened to traffic.

Discussions and Conclusion

Concrete inherently contains microcracks. When concrete is under external mechanical loadings and weather changes, these tiny cracks may slowly grow and interconnect to form macrocracks. This type of failure mechanism for micro/macrocrack development in a brittle material like concrete is well observed. Because rubber crumbs range from 0.5 to 2.0 mm (0.02 to 0.08 in.) in size, rubber crumbs may function as distributed mini control/expansion joints within the hardened concrete.6 These small elastic joints can “intercept” the microcracks and reduce the stress concentration near the tips of microcracks. Consequently, micro/macrocrack development can be expected to be delayed when rubber crumbs are present. It appears that this CRC deck project confirms an exceptional ability to resist cracking in a real-world application. The durability of the deck has been sustained for 10 years now.

In conclusion, it is hoped that this small CRC bridge deck may serve as a stimulus for additional interest in building real-world CRC applications.

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Selected for reader interest by the editors.

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	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

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