INAUGURAL LECTURE series

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UPM
UNIVERSITI PUTRA MALAYSIA
BERILMU BERBAKTI

Advancing Concrete Materials and Systems

The Search Continues

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INTRODUCTION

Concrete is essentially a very simple matrix. It is generally composed of three basic ingredients: aggregates, cement and water. Cement and water form a paste, cementing large and fine aggregates into a mass called concrete (Figure 1). Steel reinforcement is added in desired locations within the concrete mass, so that they complement each other.

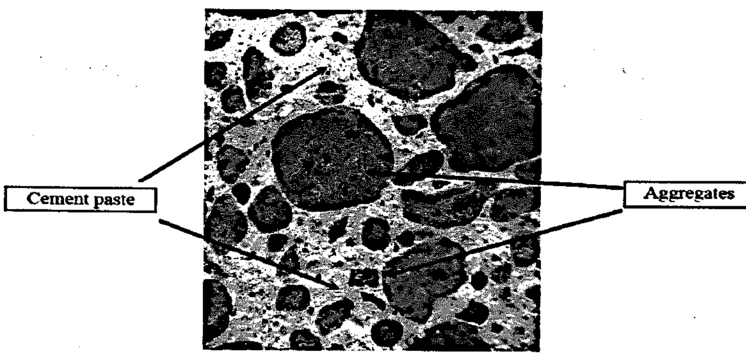


Figure 1 Concrete matrix

Concrete responds to heat, load and the environment. It can shrink, creep, crack and deteriorate. Together with steel reinforcement it acts and responds differently. Concrete takes compression well, leaving tension for the steel to handle. Concrete structures take different forms and have various functions. They can be artistic as well as functional, depending on how designers shape them. Concrete can also be ugly (Figure 2) or beautiful (Figure 3).

Although concrete has been around for thousands of years the search for new, advanced and sustainable constituent materials for concrete is still intensive. Modern days practices and use of concrete have changed. While the basic contituents remain the same, the search (and research) for new or enhanced properties continues. The need for innovative solutions can be seen from many different aspects. Apart from the need to satisfy new designs and functions for concrete structures, the energy crisis, labour issues and environmental considerations are some of the most dominant factors that push for continuous innovation in concrete technology and practices.

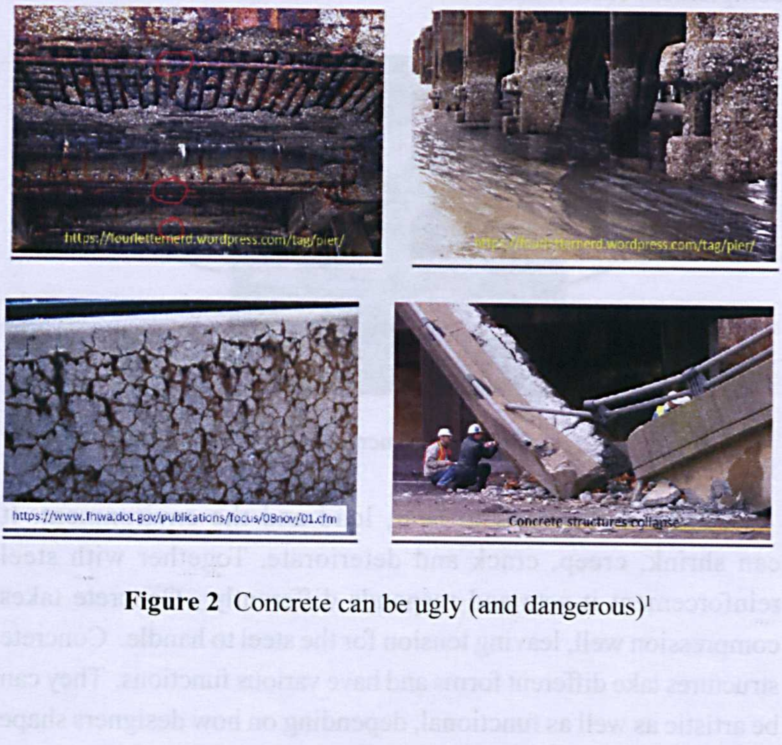


Figure 2 Concrete can be ugly (and dangerous)[1]

1 Images available online – concrete deterioration

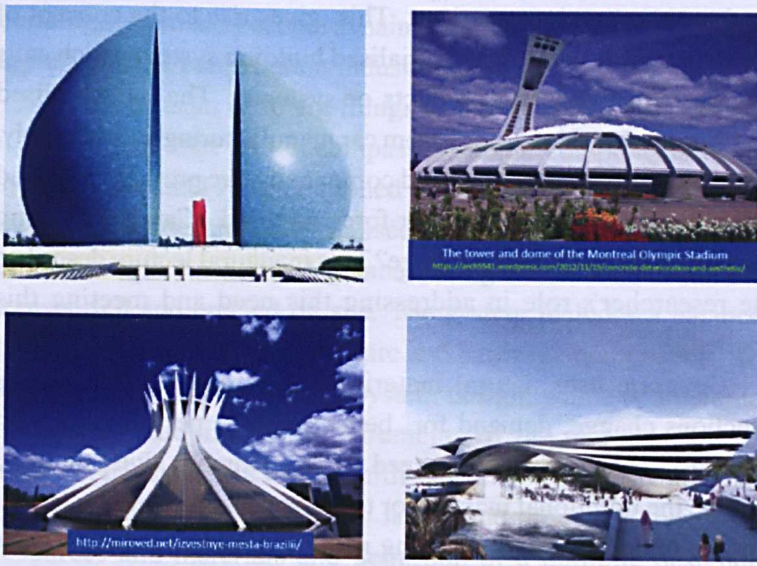


Figure 3 Concrete can represent beauty and functionality[2]

The researcher has been involved in a wide range of concrete related research and development projects. This paper will however only focus on two main areas of his research i.e. the industrialized building system (IBS) and cement replacement. His other work related to concrete deterioration and assessment, structural strengthening, integral bridges, roller compacted concrete and constructability can be found in various publications including Jaafar et al (2003), Sutan & Jaafar (2003), Thanoon et al (2005), Abdulkadir et al (2005), Khan et al (2007), Hassim et al (2008), Noorzaei et al (2009), Baghayoob et al (2010), Huda et al (2010) and Ohu et al (2012).

The need to find an innovative structural system to satisfy the IBS requirements is mainly to address the issue of insufficient local labour and to transform the practice from conventional to

2 Images available online – architectural wonders

modern construction practices. This gives rise to the concept of constructability and the industrialised building system which calls for innovative concrete products or systems. The industrialised building system takes a page from car manufacturing and assembly, where systems are designed and components are prefabricated and assembled with minimal labour force required. Can the building industry face up to this challenge? This inaugural lecture describes the researcher's role in addressing this need and meeting this challenge.

Concrete uses natural materials which are not infinite. As functions change, demand for better concrete performance also changes. Hence, there is a need to find suitable alternatives to replace the traditional material or to enhance its properties. Use of wastes, other naturally occurring materials, additives or different processes has paved the way for many possibilities. Research on various forms of concrete materials is discussed in this inaugural lecture.

INDUSTRIALISED BUILDING SYSTEMS

The concrete construction industry has several unwelcome reputations. They may be summed up, as the Construction Industry Development Board (CIDB) once classified it, as 'Difficult', 'Dirty' and 'Dangerous'. There is thus a clear need to improve the image of the concrete construction practice, as exemplified, again, by that of the car manufacturing industry. In the car manufacturing industry, a car is designed as an integrated system, but its components can be prefabricated at places other than the assembly location. This poses a big challenge for the building construction industry where the practice needs to change from conventional construction practices to that of an industrialised system. The 'industrialisation' of the building system has become a main stream agenda for stakeholders in the concrete construction industry.

IBS can mean different things to different people. However, it is accepted that IBS encompasses simple components to full systems. Junid (1986) mentioned that an IBS in the construction industry includes the industrialised process by which components of a building are conceived, planned, designed, fabricated and then transported and erected on site. The system includes a balanced combination between the software and hardware components. The software components include system design, which is a complex process of studying the requirements of the end user, market analysis, development of standardised components, establishment of manufacturing and assembly layout and process, allocation of resources and materials and definition of a building designer's conceptual framework. The software elements provide an avenue to create a conducive environment for the industrialised building system to expand.

The hardware components are categorised into three major groups. These include the frame or post and beam system, panel system and box system. The framed structure is defined as that structure which carries the loads through the beams and girders to the columns and to the ground, whereas in the panel system, loads are distributed through large floor and wall panels. The box systems include those systems that employ three-dimensional modules (or boxes) for fabrication of habitable units that are capable of withstanding load from various directions due to their internal stability. A subset of this is the supply of individual building components delivered to site and assembled to fit into a standard modular design.

The Housing Research Centre (HRC) in UPM has taken the initiative to develop several innovative solutions to address the need for the IBS. For example, residential housing is the sector with the greatest need for a quick solution. HRC has thus dedicated resources to work on systems that address the local conditions and needs, with the use of locally available materials and construction workers in the country (Kadir, M.R.A et al,,2006).

Towards this end, the development of interlocking hollow blocks and floor slab systems is the main contribution of this researcher.

Interlocking Hollow Blocks

Interlocking hollow blocks are considered to be one of the best options to address the need for industrialised building systems in the country, especially for low-rise residential buildings. The use of interlocking load-bearing hollow blocks in building construction speeds up the construction process due to the elimination of the need for mortar layers. In Malaysia, the supply of houses by both the public and private sectors is still far from meeting the demand, especially in the affordable housing sector.

The proposed system, using interlocking hollow blocks (IHB), may be the solution to overcome this shortage as these blocks can be used in the construction of both non-load-bearing and load-bearing walls. The interconnections between the blocks have to be designed to withstand the stresses from different directions at various levels, which develop in a wall under applied loads. In the development of the new interlocking block system, the following features have been identified as the main desirable characteristics:

- efficient interlocking mechanism in different directions to withstand the different forces (shear and bearing), which develop under applied loads;

- self-alignment to ensure accurate and simple construction;
- meeting modular coordination requirements;
- construction of both load-bearing and non-load-bearing walls; and
- production norms similar to that of normal hollow blocks so that the manufacturing machinery is easily fabricated.

Most existing systems using interlocking blocks have been studied. Each system has its own strengths and addresses some requirements of the industrialised building system, but none have overall features that are in line with the characteristics required. The research team in UPM has designed and tested 20 different systems (see Figure 4) and finally came up with one system that addresses the overall needs of an industrialised building system. The system, which has been named the 'Putra Block', has been patented in Malaysia, USA and the United Kingdom (Figure 5).

Details of the development, performance and application of this system for housing constructions are available in various publications, including those published by Jaafar M.S. et al, (2006), Thanoon W.A et al. (2004, 2007 and 2008) and Shafiee A.N et al. (2011). A brief summary of the system is reproduced here.

The structural properties of individual blocks, prisms and wall systems have been thoroughly investigated and properly selected to satisfy various loading conditions. The system has also been tested and satisfied the requirements for fire resistance. These interlocking mechanisms are designed in such a way that the system can behave as if the blocks have been placed using conventional mortar layers.

Stress distributions for individual and prism blocks are shown in Figure 6. The maximum compressive stresses are found near the applied load while the maximum tensile stresses are located at the top corners of the block webs where the webs support the side shell of the blocks. From these figures, it can be observed that the stress has a maximum value (compression) located at the intersections between the webs and the shells at the bottom edge of the top stretcher block. This is a result of connecting two different geometric configurations of blocks, i.e. the stretcher and the half blocks, as well as due to the connecting of different element sizes. The tension zones are confined to the top of the webs in a way similar to that in a block unit. The stresses at the top of the webs of the stretcher and half blocks are found to be in tension due to the interaction between the shells and the web (action and reaction).

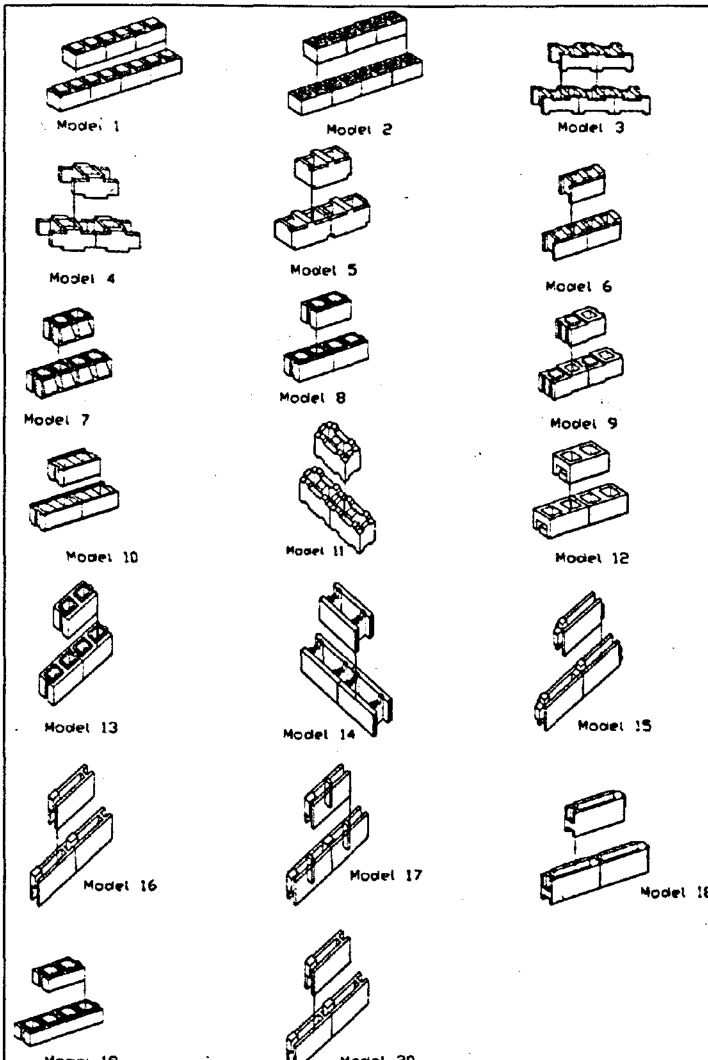


Figure 4 Different interlocking hollow block models studied at Universiti Putra Malaysia

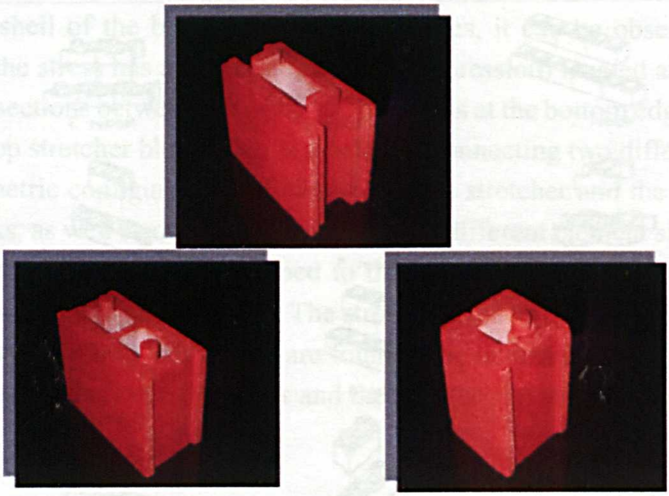


Figure 5 Putra Interlocking Block System

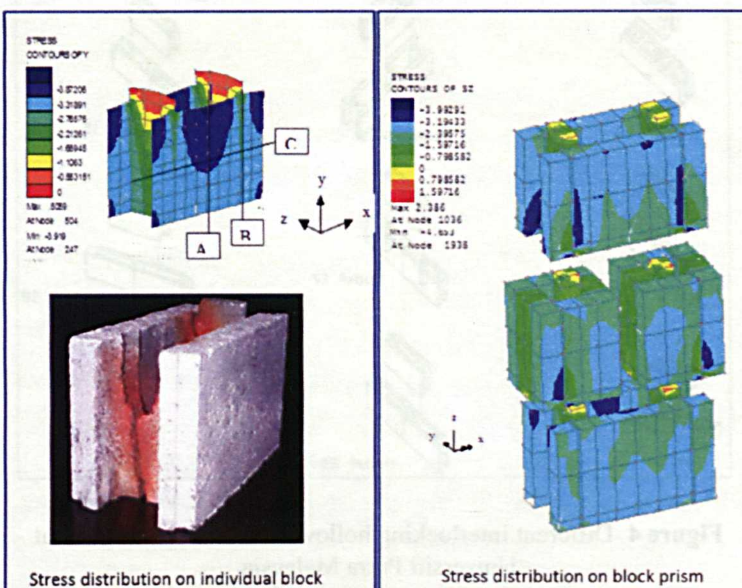


Figure 6 Stress distribution for individual blocks and prisms

The block dimensions mentioned are in conformity with the modular design rules, which require the horizontal controlling planes to be in modular dimensions of 3M or 300 mm, and the vertical controlling planes to be 1m or 100 mm. The Half Block with 150 mm length can be conveniently put in the technical zones of 150 mm. This allows other spaces in the house to have modular dimensions, thus facilitating the use of other modularly coordinated components such as windows, doors and built-in cabinets. It can also be seen that if the typical room heights of 2800 mm or 3000 mm are adopted, there is not a single block that needs to be broken to fit into the spaces required. There will be no wastage of materials, and indeed, the exact number of blocks required for a specific house can be estimated from the architectural drawing.

Walls can also be constructed using minimal unskilled labour. In addition, the assembled blocks in the wall provide continuous hollow voids, which can be used to host stabilising ties in vertical and horizontal directions to enhance the stability and integrity of the system. At the corners or junctions of walls, the connectivity between layers is achieved at subsequent layers, as shown in Figure 7. This interlocking hollow block system, has been employed efficiently to construct a single-storey house, as shown in Figure 8. Reasonable weight and simple shape of the blocks render the system friendlier to the workers.

Various experiments have been carried out to determine the material properties and structural performance of the blocks. The experiments included:

- Individual Blocks;
- Prisms;
- Basic (Standard) Panels;
- Comparison between cube, individual block, prism and basic wall panel;

- Failure mechanism;
- Effect of slenderness on wall behaviour;
- Effect of eccentricity on wall behaviour;
- Crack pattern and failure mode; and
- Fire resistance.

The innovative tests set up for the interlocking mechanism, shear-load slip mechanism and individual block stress-strain properties are shown in Figures 9 -11. Test results have shown the efficacy of the interlocking mechanisms to avoid the need for mortar layers. This leads to ease of wall construction. The system also performs well under different loading conditions and fire.

Simplified design procedures have also been developed using the system and examples for different wall slenderness ratios under different eccentricities are shown in Table 1.

The following conclusions are made based on the extensive theoretical and experimental investigations that were carried out:

a. The interlocking mechanism is capable of replacing the mortar layers traditionally used in masonry wall construction. It plays a significant role in the distribution of stresses that develop in the block due to the applied load;

b. The theoretical and experimental investigations indicate that the system may be used for the construction of load-bearing masonry walls for single and double-storey residential buildings;

c. Design formulae have been developed for the design of load-bearing walls having different slenderness ratios and subjected to different load eccentricities;

d. A single-storey prototype house has been designed and constructed at UPM indicating that the system can be used efficiently.

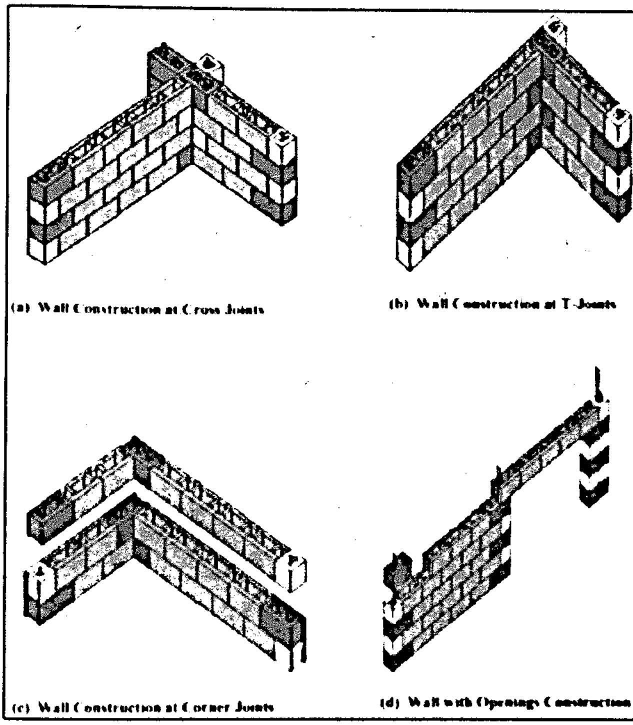


Figure 7 Schematic drawing for corner walls and walls with opening construction.

Figure 8 Example of house construction using the Putra Block System

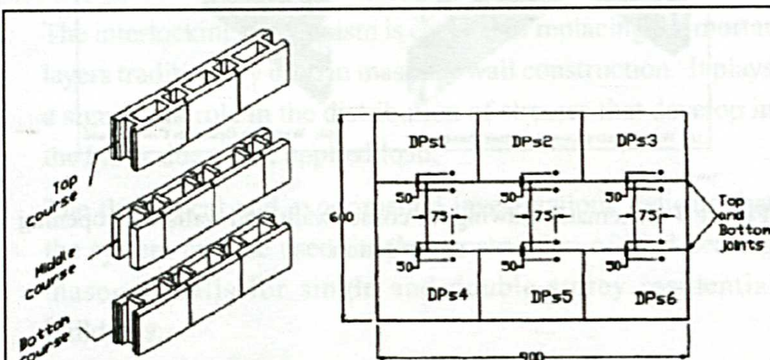


Figure 9 Innovative test set up for interlocking mechanisms

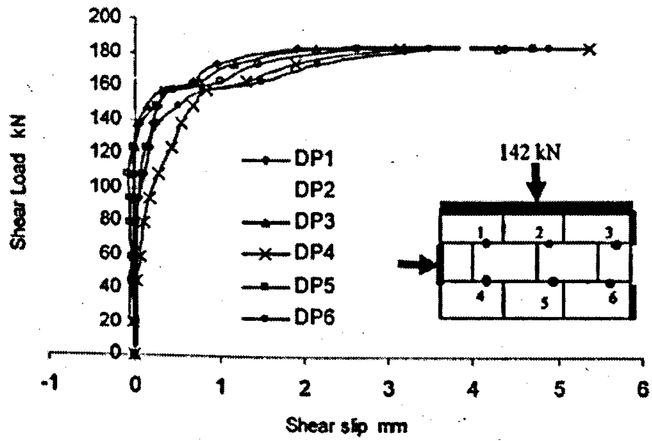


Figure 10 Shear-load slip behaviour

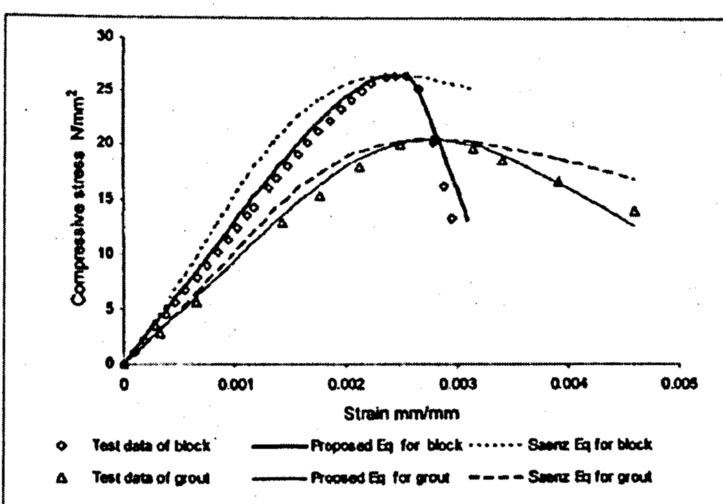


Figure 11 Proposed stress-strain relation for block and grout

Table 1 Proposed capacity reduction factor for the Putra Block

Group I		e/t	Capacity Reduction Factor			Discrepancy %	
			FE Model	Proposed Eq	BS	FE Model & Proposed Eq	Proposed Eq & BS
SR=8		0.00	0.576	0.598	0.450	4.0	24.8
		0.12	0.500	0.492	0.371	-1.7	24.6
		0.23	0.434	0.404	0.222	-7.0	45.1
		0.37	0.289	0.323	0.198	11.5	38.7
SR=12		0.00	0.501	0.496	0.349	-1.0	29.7
		0.12	0.436	0.418	0.306	-4.2	26.7
		0.23	0.371	0.352	0.185	-5.3	47.4
		0.37	0.272	0.289	0.167	6.2	42.1
SR=16		0.00	0.405	0.412	0.320	1.6	22.3
		0.12	0.360	0.355	0.276	-1.4	22.2
		0.23	0.308	0.306	0.183	-0.6	40.2
		0.37	0.261	0.258	0.165	-0.9	36.1
SR=20		0.00	0.336	0.341	0.315	1.7	7.7
		0.12	0.309	0.301	0.273	-2.5	9.4
		0.23	0.243	0.266	0.181	9.4	32.0
		0.37	0.237	0.231	0.165	-2.5	28.5

Precast Slab System

Floor systems complement the development of interlocking hollow block systems and form part of the requirement for a complete industrialised building system. A slab structure occupies the biggest percentage of total dead load and volume for an ordinary residential structure. A simple load calculation for a residential building shows that approximately 40 - 60% of dead load is the self-weight of the slab structure [Yavuz Y., 2008]. Thus, approximately 10% of self-weight reduction from floor slabs may lead to five percent of self-weight reduction for the entire building. Moreover, it directly faces the live load and transfers the load to the beams and columns.

The traditional solid precast slab is found to be challenging for large scale projects because of its heavy self-weight, which leads to dependency on heavier equipment, transportation difficulties and expensive connections and joints solutions. In addition, heavy precast slabs need extra temporary supports during construction and larger beam and column size, which result in the escalation of the overall cost [Kim S. Elliott, 2002].

More than 15 different types of precast slabs have been used successfully in the construction industry. Five general criteria have to be considered for the capacity of flooring units: bearing capacity, shear capacity, flexural capacity, deflection limits and handling restriction [Kim S. Elliott, 2002]. There is no system which fulfills all of the above mentioned criteria.

In terms of better structural performance and lower cost, the development of varieties of light weight slabs has become a crucial need. The use of semi-precast panels is increasing rapidly due to its versatility in transportation, handling and effective joint practice. In the recent past, a large number of semi-precast panels have been developed using either ferrocement or composite cold steel deck with different types of toping concrete [Tasomorodion I., 1983; Kaushik SK et al., 1991; Hago A.W., 2005; Ahmed E. & W. Badrozaman, 2002]. Insulating and light weight core panels were then developed, which greatly increased the desirability of this type of construction material. The panel consists of two thin skins of high strength layers and elastic moduli separated by a core thick layer of normally much weaker and lower material density [Salmon C.D. & Amin E., 1997; Salmon C.D. et al., 1997; Amin E et al., 1994;].

Composite slab systems have been found to be structurally effective with a thin layer of precast member taking into account the benefits which include: shorter construction time, less dependence on heavy equipment at job sites, less material wastage, high quality smooth surface finish, *in situ* structural concrete topping and in-fill forming monolithic structures, elimination or great reduction in the need for props and elimination of conventional formworks [Algirdas

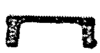
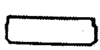
K. et al., 2007; Kubaisy M.A. & Zamin J, 2000; Kubaisy M.A. & Zamin J, 2001; Lee S.L. et al, 1990; A.E. Naaman, 2000].

Thinner precast structure of the composite slab can be achieved with Ferrocement technology. Ferrocement has been observed to provide considerable reduction in cracks and their spacing (64 - 84%). Additionally, it enhances the ductility and energy absorption properties [Yavuz Y., 2008]. Ferrocement is not only an extension of reinforced concrete but is now also considered a member of the family of laminated composites. It can be reinforced with steel or non-metallic meshes such as fiber reinforced polymeric (FRP) meshes [Kubaisy M.A. & Zamin J, 2001]. The addition of fibers or micro-fibers as secondary reinforcement in the cement matrix, to improve performance, makes Ferrocement a hybrid composite. A summary of the weight and size of the existing precast slab system is presented in Table 2.

Precast and cast *in situ* layers of existing systems are connected with 2D or 3D shear trusses. The shear trusses are used as a handling location during transportation and construction. However, this connection system has been questioned by many researchers for their capacity to carry horizontal load without any separation and horizontal cracks (Sittichai, 2003; Alfred, 2001; Engstrom, 1982). Moreover, the ability of the shear trusses to be shear connectors for two layer composites is yet to be explored.

This study introduces a semi-precast floor slab system, the Ferrocement-AAC composite slab, to address some of the abovementioned shortcomings in existing systems. The new system consists of a bottom Ferrocement skin, AAC masonry and *in situ* mortar ribs (Figure 13). The Ferrocement layer is the precast part of the composite slab, which consists of a wire mesh and steel reinforcement, required to resist tensile stresses. The thickness and reinforcement of this layer will depend mainly on the span of the slab. The AAC layer and the *in situ* ribs provide the necessary resistance to the compressive forces developed due to bending. The two layers are interconnected using interlocking and rough surface between the precast and cast *in situ* layers.

Table 2 The Sizes and Weights of Main Types of Precast Floors (Arnold 2004)

Floor type	Reinforcement	Max. span (m)	Structural depth (mm)	Most common width(mm)	Unit weight (kN/m²)
	Reinforced and prestressed hollow core elements	9	100 - 300	300 - 1200	2.0 - 4.0
	Prestressed hollow core elements	20	120 - 550	200	2.0 - 4.8
	Prestressed double-T elements	24 (30)	200 - 800	2400	2.0 - 5.0
	Prestressed inverted-U elements	9	150 - 300	600	1.5 - 3.5
	Reinforced and prestressed massive slab	6	100 - 250	300 - 600	0.7 - 3.0
	Composite floor-plate floors	7	100 - 200	600 - 2400	2.4 - 4.8
	Beam and bloc floors	7	200 - 300	200 - 600	1.8 - 2.4

The main advantage of this system, amongst others, is its relatively lighter weight compared to R.C which will reduce the load transferred to the beams or walls. The masonry AAC acts as light, effective insulation material and at the same time partially resists the compression forces developed due to bending of the composite. On site, the construction of the composite slab does not require heavy equipment to handle the Ferrocement layer. Furthermore, the construction does not need any formwork since the bottom layer of

Ferrocement is a precast unit that can be easily fixed in position, using a simple crane, to provide a platform that acts as a formwork for the brick layer and the *in situ* concrete ribs. This experimental study is limited to the investigation of the structural performance of the one way Ferrocement-AAC composite slab subjected to two-lines loading. The study highlights the effects of the AAC layout on its overall structural response in terms of load–deflection characteristic, ductility, strain distribution, composite action and failure load. The test set-ups for flexure and shear are shown in Figures 13 and 14, respectively. Figure 15 shows a simple test set up to demonstrate the system's strength.

The proposed composite slab can be used as a structural floor for residential buildings. The dead load of the slab can be reduced by 23–32% by using the proposed composite slab compared to the solid RC. The number of longitudinal ribs has a significant effect on the ductility as the specimens with four longitudinal ribs show 60% and 28.4% increase in ductility compared to the slab specimens with two and three longitudinal ribs respectively. Based on strain monitoring the slabs performed in a fully composite manner until the ultimate load. There were no horizontal cracks observed between the two layers of the composite slabs at any stage of loading. All the slab specimens show ductile behaviour. Ductility and maximum deflection of the slabs are good enough to give ample warning before failure.

Details of the development and performance of the proposed system are available in Thanoon A.M.T. et al. (2008, 2010, and 2011), Yardim Y. (2008) and Yardim Y. et al. (2013).

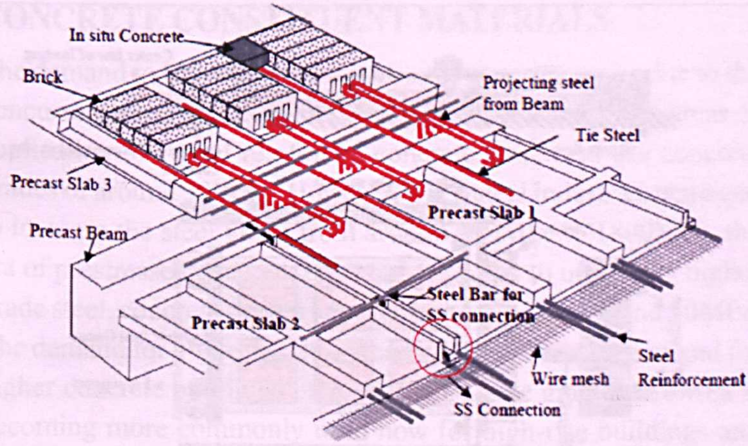


Figure 12 Proposed Ferrocement-AAC composite Slab

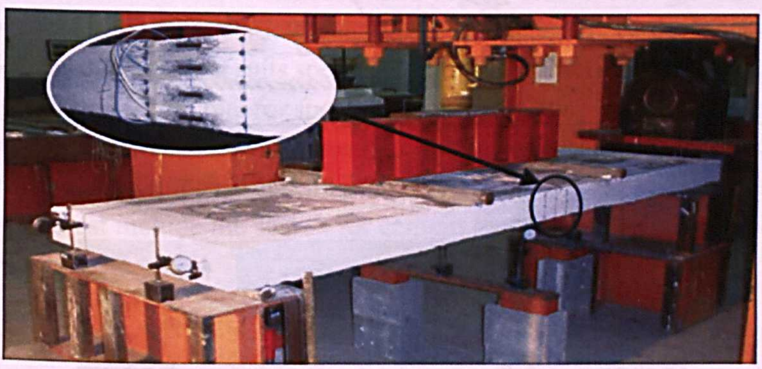


Figure 13 Test set-up for flexural performance

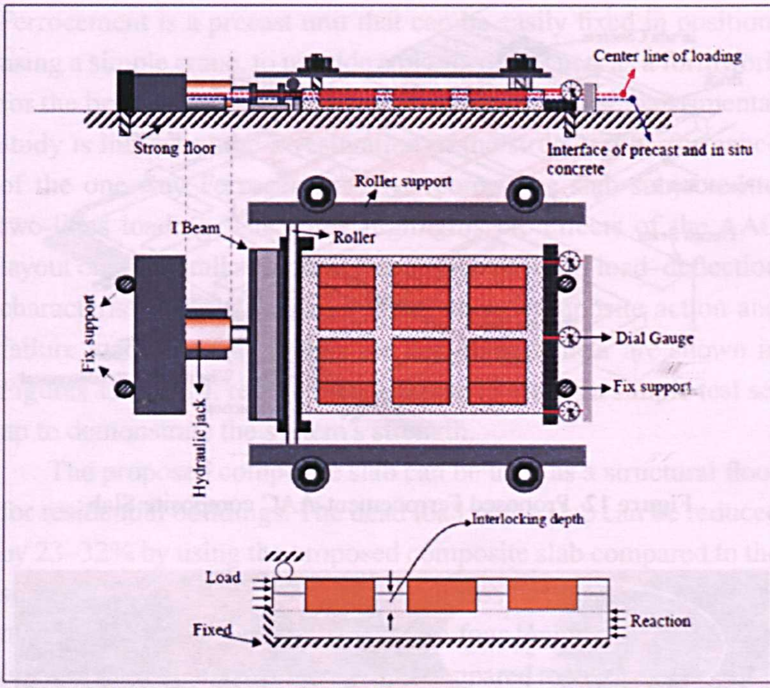


Figure 14 Test set-up for shear keys

Figure 15 Simple performance test demonstrates the strength of the proposed system

CONCRETE CONSTITUENT MATERIALS

The demand to improve the properties of concrete arises due to the concurrent development of other materials as well as new areas of application. Normal reinforced concrete structures use concrete grades of around 30MPa. However, when steel industries managed to increase the steel grade from around 400MPa to 1800MPa, the era of prestressed concrete emerged. In order to utilize the higher grade steel, concrete grades need to be increased to around 50MPa. The demand for higher grade concrete continues as the demand for higher concrete buildings increases. Concrete grade of 80MPa is becoming more commonly used now for high-rise buildings and long-span structures.

Compressive strength is not the only property that matters for concrete structures. Durability and higher tensile strength have become important characteristics that are sought after by engineers. Special concrete that suits special requirements is steadily replacing conventional concrete for special structures. Thus, research efforts by this researcher have focused on finding suitable materials and processes to enhance the properties of concrete. The main areas of interest include the search for cement replacements and special concrete.

Cement

Cement is the most important ingredient that determines the quality of concrete. Its content has significant implications on the strength and durability characteristics of concrete.

The manufacturing of Portland cement consists of grinding of calcareous materials (limestone or chalk) and argillaceous materials (clay or shale) in certain proportions and mixing and burning them in a kiln at temperatures of about 1450 °C to form clinker. The clinker is cooled and ground to powder fineness with three to five percent of gypsum added. There are two processes for cement production, which are the wet process and dry process, but, there are no significant differences in the final products. The dry process is however more economical than the wet process.

The raw materials used for the production of Portland cement consist mainly of lime, silica, alumina and iron oxide. During the heating stage, these oxides interact with one another to form complex compounds, namely, tricalcium silicate (C_3S), dicalcium silicate (C_2S), tricalcium aluminate (C_3A) and tetracalcium aluminoferrite (C_3AF). Portland cement consists of four main components, which are, tricalcium silicate (C_3S), dicalcium silicate (C_2S), tricalcium aluminate (C_3A) and tetracalcium aluminoferrite (C_4FA). When the cement comes into contact with water several chemical reactions occur with its components.

The first two components, C_3S and C_2S (i.e. 75% of the dry Portland cement) are the main cementitious components in the Portland cement. The products of calcium silicate hydration are non-crystalline calcium silicate hydrate (C-S-H gel), which is responsible for the strength and calcium hydroxide (CH), which remains active for additional reactions. Two main reactions that are the subject of ongoing search for better concrete properties are:

$$C_3S + 5.3H \rightarrow C_{1.7}SH_4 + 1.3CH \qquad (1)$$

$$C_2S + 4.3H \rightarrow C_{1.7}SH_4 + 0.3CH \qquad (2)$$

More CSH gels means better strength. Less CH means more durable concrete. The search for better concrete properties is focus on finding ways and means to increase CSH and reduce CH content. From the equations, it is clear that in order for the CH to further react and form CSH, silica must be added. However, the challenge remains that not all silica will react under ambient condition to form CSH.

Cement Replacement

The worldwide production of cement accounts for almost 7% of the total world CO_2 production, and from the projections made by the cement companies, this proportion is expected to remain steady in future decades. The net world cement production was estimated to be about two billion tons in year 2010 [Malhotra, V. (2000].

Portland cement is a high energy and resource consumer product. Therefore, to conserve resources and save energy, many attempts are being made to find substitute materials for partial replacement of cement. Fly ash (FA), silica fume (SF), ground granulated blast furnace slag (GGBS), metakaolin (MK), rice husk ash (RHA) and sugar cane (SC) are some of the most common supplementary cementitious materials used in the concrete industry.

A pozzolan may be used with lime or with Portland cement to make mortars and concrete. In the case of the latter, the pozzolan reacts with the calcium hydroxide (CH) produced from the hydration of the Portland cement. This reaction produces denser concrete and develops secondary cementitious properties due to the pozzolanic reaction.

Many efforts have been made to review the usage of pozzolan materials as partial cement replacement. V.M. Malhotra [Malhotra, V., 1993] presented the use of silica fume, fly ash, rice husk ash and slag in concrete production while industrial slag in high performance concrete was reviewed by C. Shi and J. Qian [200] and S. Chandrasekhar et al., [2003] reviewed rice husk ash as the source of reactive silica Meanwhile, metakaolin and calcined clay were covered by B.B. Sabir et al. [2001] and R. Siddique and J. Klaus [2009].

Pozzolan materials may be divided into natural and artificial pozzolan materials. The natural pozzolan materials include all pozzolan derived from volcanic rock, diatomaceous earth and koalin. Natural pozzolan materials may or may not require further treatment. The second group comprises by-products of pozzolan materials where they can be obtained as industrial by-products such as silica fume, fly ash, ground granulated blast furnace slag or from agricultural wastes such as sugar cane and rice husk. By-product materials also may or may not require further processing to be used as cement replacement materials [Mehta, P. K., & Monteiro, P. J. M., 2006].

According to their pozzolanic and/or cementitious activity, pozzolan materials can be classified into four categories. Firstly, materials possessing cementitious properties such as GGBS; the second category is high-calcium fly ash, which possesses cementitious and pozzolanic properties, while the third category possesses high pozzolanic reactivity, which can be found in silica fume, rice husk ash and metakaolin. Low-calcium fly ash and other natural materials possessing normal pozzolanic properties are classified in the last category [Mehta, P. K., & Monteiro, P. J. M. 2006].

Papadakis et al. [2006] found that pozzolan materials require CH in order to produce strong products, whereas a cementitious material itself contains quantities of CaO and can present self-cementitious activity. The quality and quantity of active pozzolan depend mainly on two parameters, the amount of lime that combines with the pozzolan and the rate at which such a combination occurs [Hewlett, P. C., 2004]. The amount of combined lime depends on the nature of the active phases, their content in the pozzolan, their SiO_2 content, the lime/pozzolan mix ratio and the length of the curing period. Further, the factors associated with the rate of combination are specific surface area of the pozzolan, water/solid ratio and hydration temperature.

The existing pozzolans are becoming more expensive than the Portland cement itself; hence there is a need to find alternative materials as partial cement replacement. Silica powder or micro silica is found in abundance in some countries. It comes in the form of dune sands (DS) or white sands (WS) (Figure 17). These naturally occurring materials are rich in silica content and have huge potential. They have thus been the subject of interest in this sector.

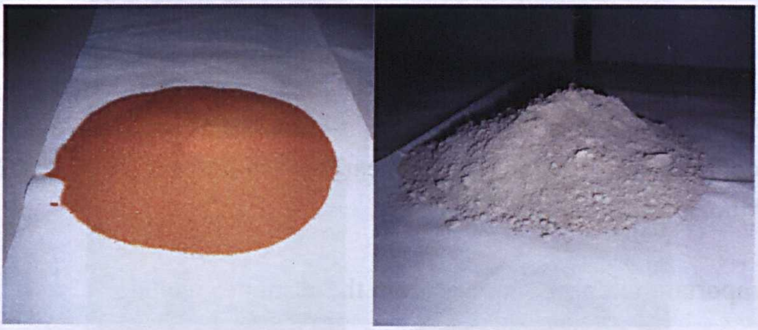


Figure 16 Natural and processed dune sand

A summary of existing pozzolans had been presented at the World Engineering Congress by Alawad OA et al. (2010). The scanning electron micrographs of different pozzolan materials, together with dune sands are shown in Figures 18 and 19.

Extensive study has been conducted on dune sand, from its characterization to its treatment and effects on concrete properties. The research work is identifying:

- suitable activation methods - chemical, mechanical or heat treatment;
- suitable curing methods - moist curing, low pressure steam method or high pressure steam method;

- effects of different activation and curing methods through various physical and chemical tests including strength, chemical attack, shrinkage and permeability test; and
- effects of different activation and curing methods through microstructure examination techniques including Scanning electron microstructure (SEM), X-ray diffraction (XRD), Thermo-gravimetric (TG) analysis, and Diffraction thermal analysis (DTA).

The studies also include identification of ternary elements where micro silica can be used to the maximum, while reducing Portland cement to the minimum. Some of the results have been reported in various journal publications (Jaafar M.S. et al., 2002; Alhozaimy A. et al., 2012, 2013).

Important findings obtained from these studies include:

- the possibility of using DS and WS as 30% partial cement replacement under autoclaved curing. The temperature and pressures allow for pozzolonic activity to take place for the dune and white sands, as shown by the strength test results and the microstructural analyses;
- with autoclave curing, all of the binary and ternary mixtures yielded mortar with a compressive strength higher than that of the control sample. The autoclave-cured ternary combination of 30% GDS, 50% PC and 20% GGBS showed the highest compressive strength;
- the possibility of using a PC content as low as 10% since the mixture of 30% GDS, 10% PC and 60% GGBS displayed strength comparable to the control sample;

- the possibility of reducing the PC content by up to 90% by incorporating GDS and GGBS in autoclave-cured mortar mixtures.

These findings have significant implications for the sustainability and economy of concrete construction in countries with abundant supplies of natural dune sands.

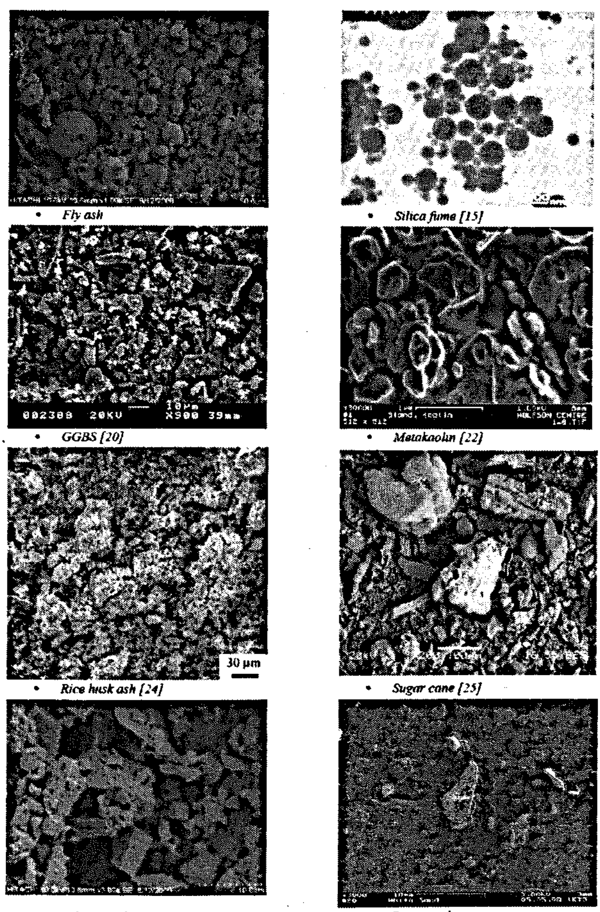


Figure 17 (a) - (h) Scanning electron micrographs (SEMs) of pozzolan materials

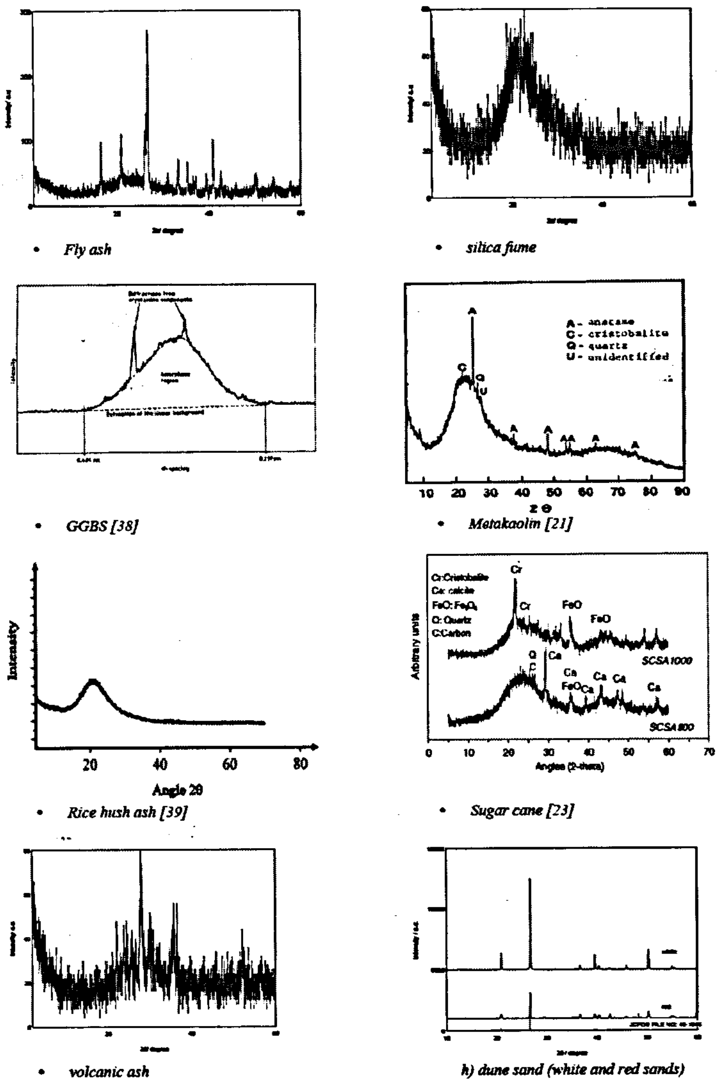


Figure 18 (a) - (h) X-ray analysis of pozzolan materials

Blended Cement

Concrete containing blended cement has experienced rapid growth in the construction industry. It has the potential to save energy as the naturally occurring materials are less energy intensive. Therefore, many attempts are being made to find substitute materials that can be used as a partial replacement for PC. Supplementary cementitious materials (SCMs) such as fly ash (FA), silica fume (SF), ground granulated blast furnace slag (GGBS), metakaolin (MK) and rice husk ash (RHA) are some of the most common PC replacement materials currently used in the concrete industry. The incorporation of these materials provides many benefits including technical, economic and environmental benefits. The technical benefits include the enhancement of fresh concrete properties and finished concrete with increased ultimate compressive strength and improved impermeability and durability.

The SCMs are alumino-silicate materials that react with calcium hydroxide (CH) at ambient temperature in the presence of moisture to form the cementitious calcium silicate hydrate (CSH). This action will result in the reduction or removal of CH from the concrete composite, hence, it has a positive effect on the durability and transition zone between cement paste and aggregate. Apart from their chemical effects, SCMs help to fill the capillary pores between cement grains and thus improve the density of the cement paste.

GGBS, unlike other SCMs, consists of chemical oxides similar to those in PC but in different proportions. Many studies have been conducted on the use of GGBS as an SCM and it has been reported that GGBS-supplemented concrete shows a lower early strength gain compared with plain concrete. Therefore, GGBS is not used in applications where high early strength is required. However, when GGBS is added in combination with PC, the hydration of GGBS is accelerated due to the presence of CH and the sulfate compound gypsum in the PC. It has also been reported that the reactivity of GGBS is improved at elevated temperatures as in the case of thermal curing, which is largely used in the precast concrete industry. With the advantage of GGBS and coupled with the potential of dune sand to be used as cement replacement, a study where these materials are blended was proposed.

The study (Alawad, O.A. et al., 2014 and Alhozaimy, A. et al., 2013) was to investigate the effect of using ground dune sand (GDS) as a cement replacement material in binary and ternary combinations with PC and GGBS on the fresh properties and compressive strength of mortar. The successful use of GDS to reduce cement consumption can have a potentially significant impact on the sustainability and economy of concrete construction, especially in countries with unlimited supply of natural dune sands. The findings of this study may be beneficial for the wider application of dune sand as a cement replacement material in precast concrete, thus reducing PC consumption.

The study concluded that partial substitution of PC with GDS in binary blended cement does not significantly affect the fresh properties of the pastes or mortars. However, increasing the GGBS content leads to an increase in the water required to achieve the normal consistency, but this has only a minor effect on the setting time. As the content of GDS is increased in the binary mixtures, the compressive strength decreases with standard curing, however, with autoclave curing, the compressive strength is improved. The highest compressive strength is achieved with 30% of the PC replaced with GDS. All of the binary and ternary blended mixtures develop greater compressive strength than the CTRL mixture when autoclaved. The combination of 30% GDS + 50% PC + 20% GGBS yields the highest strength under autoclave curing conditions. However, the study shows that it is also possible to reduce the PC content by up to 90% by incorporating GDS and GGBS in autoclave-cured mortar mixtures. This finding has significant implications for the sustainability and economy of concrete construction in countries with abundant supply of natural dune sands.

CONCLUSION

This inaugural lecture highlights the increasing importance of concrete as a construction material in the contemporary building industry. It also discusses in detail the constituents of concrete, among which is Portland cement, and the ongoing research to find better and more economical substitute constituents for the manufacture of Portland cement.

In the discussion on concrete and the construction industry the concept of the Industrialised Building System (IBS) is used as a suitable replacement for conventional construction approaches that are saddled with problems like shortage of local labour, poor turnaround time and economic non-viability.

The IBS is a concept that involves the prefabrication of construction components, modules, interlocking hollow blocks and even heavy concrete slabs off-site, which are later transported to the building site to be easily and quickly erected or assembled. This does not require highly skilled labour, is cost effective and time saving.

However, even as concrete continues to be a crucial and integral component of the construction industry, and the IBS gains acceptance as a superior construction approach, the search for better performing constituents of concrete continues. This is because any improvement in the quality and performance of concrete will have a wide-ranging impact on the construction industry due to the critical role in plays in the industry. And, thus the search continues.

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BIOGRAPHY

Family and Academic Background

Mohd. Saleh Jaafar was born on 3rd. May 1963 in Kg. Kandang, Melaka. He is the 12th. child among the 18 children born to Hj. Jaafar Yon and Hjh. Embok Chik Alias. His father was a barber and paddy farmer. His mother was a homemaker who received the IBU MITHALI (exemplary mother) award from the Melaka State Government in 2005. Life was tough, but that taught Saleh so many things about life and the true meaning of gratitude. He is married to Cikgu Rasilah Sampul and they have been blessed with 7 children, currently aged between 10 to 27 years.

Saleh was the top student from primary to the upper secondary school levels. He obtained a BSc (Civil Engineering) with honours from Michigan State University in 1985 (ranked 3rd. in his class of 80 graduates). He was a member of Chi Epsilon, a national Civil Engineering Honour Society in USA. He received his MS (Structures) from the Univ. of Michigan at Ann Arbor in 1988, and PhD from Sheffield University, UK in 1998.

Academic Leadership – Positions and Achievements:

Saleh joined the Civil Engineering Department in UPM in 1985 as a tutor, and later as a lecturer in 1988. He was promoted to Associate Professor in 2001 and Professor in 2009. Upon completion of his PhD, Saleh was appointed as the head of the Civil Engineering Department from 1999 to 2006. He was a Deputy Dean (Academic) at the Faculty of Engineering from 2006-2007, and the Dean of Engineering from 2007-2010. Saleh was later appointed as the Deputy Vice Chancellor for Research and Innovation at UPM from 2011 to 2013.

During his nearly seven years of leading the Department of Civil Engineering, UPM, he managed to enhance the productivity of staff members in research and teaching. As part of the Eighth Malaysian Plan (2000-2005), the department managed to obtain about RM12 million in research grants. Journal article publication by members of the department steadily increased from 0.2 journal articles/staff/year in 2000 to over 2.5 journal articles/staff/year in 2005. The Civil Engineering Department, UPM is now among the world's top 150 in QS subject ranking.

He led the faculty in the design, implementation and monitoring of Outcome Based Education (OBE) programmes and was at the forefront in helping the faculty to develop its strategic plan, key performance indicators and a quality assurance system for ISO certification. He also led in the development of a much sought after system for myOBE™ to manage OBE implementation. When he was the Dean of Engineering, the quantity and quality of publications by faculty members increased from 250 in 2007 to 400 in 2009. The total impact factor (measured by Thomson ISI) also increased from 90 in 2007 to 215 in 2009.

On his appointment as UPM DVC (Research and innovation) in January 2011, he introduced and implemented several strategic initiatives to strengthen research and innovation at UPM. The initiatives included:

- Introduction of the RDCE ecosystem for excellent and sustainable research: developing research clusters and research working groups to work on program based research across faculties and institutes;
- Comprehensive training to produce staff with innovative mind sets, collaborating with SRI International for value creation;
- Strengthening strategic laboratories and infrastructure to reach

world class status with proper certification. The number of labs certified increased from 2 to 15, and is expected to increase to 50 by 2015;

- Introduction of EDU Tourism as a platform for UPM technology showcase under the Edu-Park initiatives; and
- Introduction of UPM-Innohub as a platform to produce start-up companies based on UPM technologies and know-how.

UPM continues to generate research grants worth more than 70 million per year. The university received the national award for innovation in 2012 and had the highest scores for innovation under the Malaysian Research University assessment 2010-2012. UPM was in the top 2 under MyRA 2010-2012 evaluation and has increased its CIJ from 2000 in 2010 to nearly 3000 in 2013.

Under the Edu-park initiatives, eight locations in UPM, which showcase UPM expertise and technologies, have been identified by the Ministry of Tourism as meeting the standards of tourist attractions. These locations have received a few thousand visitors since their inception in mid-2012.

Saleh also strengthened UPM Press by bringing all faculty based journals under the DVC's office in order for UPM journals to be indexed in Scopus/ ISI databases.

Saleh believes in bringing out the best from people and believes everyone can create value for the organisation. His leadership style can be summarised as Listen, Learn and Lead – a style adapted from his alma matter.

Saleh believes in bringing out the best from people and believes everyone can create value for the organisation. His leadership style can be summarised as LIsten, Learn and Lead - a style adapted from his alma matter.

Research Experience

He has been involved with researchers in the Housing Research Centre, UPM since 1997 and carried out research on a wide range of topics related to concrete structures, from materials' characteristics to structural behaviour and performance. His past and current research interests include the development of the industrialised building system (IBS), RC and PSC structural behaviour and strengthening, high performance concrete, non-destructive tests for concrete structures and integral bridges. He has been involved in 16 research projects with grants totalling more than RM5mil. He leads seven of these research projects and the sponsors are government and private agencies, including a research project funded by King Saud University, worth RM1.8million. Saleh has supervised and co-supervised 16 PhD candidates, 37 MSc researches, 30 MS projects and over 40 BS students. To date, he has published over 200 articles, of which over 90 are in citation indexed journals. He has over 435 citations from a total of 98 indexed journals (over 4 citations per paper) and his current H-index is 13. He also has patents granted in Malaysia, UK and US for his research work on IBS and cement replacement materials.

Professional Experience and Contributions

Saleh has had professional experience through his involvement with Civil & Structural consultancy firms such as Kemasepakat Sdn. Bhd. and Gabungan Jurubina. He has been involved in building and bridge design, structural assessment and rehabilitation. He has been a registered Professional Engineer (P.E) since 1993 and was a non-executive director for JNA Consulting Engineers and advisor to Galas Consulting Engineer. He has also provided consultancy services to Zaidun & Leng Consulting Engineers, Perunding Bersatu and ICP Sdn. Bhd. Saleh has often been invited to give talks and conduct workshops to practising engineers and professionals.

At the national level, he was actively involved with the Engineering Accreditation Council as Panel member and associate director to help Malaysia obtain the Washington Accord Signatory member status in 2007. He is a Fellow of the Institution of Engineers, Malaysia (IEM) and has served as its council member for two terms. He led the development of a rating and quality assessment instrument for private colleges (MyQuest) which has been adopted by the Ministry of Higher Education since 2010. He has also been entrusted with chairing many national initiatives and committees, including MAPIM, MQA guides for Assessment, PoPBL training for trainers modules, Research Acculturation and Collaborative Effort (RACE), and the selection Committee for Anugerah Akademi Negara (Teaching & Learning). He was served as Deputy Chairman for the working committee, in the development of the Malaysia Education Blueprint 2015-2025 (Higher Education). He is now serving as the Director for the University Transformation Programme, Ministry of Higher Education, Malaysia. Saleh has also been serving as Science Council member for MARDI since 2012.

At the international level, he is a founding member of the European Silk Roads University Consortium (ESRUC), University Network for Tropical Agriculture (UNTA) and a coordinator for ASEAUNINET. He is a member of the American Association of Civil Engineers (ASCE) and European Association for International Education (EAIE). He has established networks with many universities in Turkey, Central Asia, Middle-east and Europe. He was made Chair for the drafting committee for the Kuala Lumpur Declaration for TVET in the UNESCO Asia Pacific Conference for Education and Training 2015.

ACKNOWLEDGMENT

In the name of Allah, the Most Gracious and the Most Merciful.

First praise is to Allah, the Almighty, on whom ultimately we depend for sustenance and guidance. I can never thank Him enough for all that He has given or not given me, and for bringing me to this stage of my life.

I am forever grateful to the Malaysian government for providing me endless opportunities to succeed and contribute. The scholarships for all my studies had been duly provided by the government and its agencies. I am extremely grateful to UPM for believing in me and giving me opportunities to make mistakes, learn and grow. My sincere appreciation to all my former school teachers at Sekolah Tun Mutahir and Sekolah Menengah Munshi Abdullah, supervisors at the University of Michigan at Ann Arbor and Sheffield University for the teaching and guidance that made me who I am today. Special thanks to all former heads of department, deans of faculty and vice chancellors of UPM for giving me the platform and space to develop and express myself, the best way I can.

I am always grateful to have been blessed with good friends and colleagues, especially those in the Civil Engineering Department. I am especially grateful to all members of my research team - Dr. Razali, Dr. Waleed, Dr. Jamaloddin (Alfatihah), Dr. Farzad, Dr. Farah, Prof. Abang Abdullah and Ir. Salihudin – they have been instrumental in the success of my academic and research journey. My academic life would not have been complete without the wonderful students I have had – Omer, Yavuz, Shibli, Norsuzalina, Ahmad Najm, Aeid, Ahmad Alwathaf, Norazizi, Khaled, Rachel Chong and Paknahad, amongst many others.

Special thanks to the many external organizations which have helped me grow in my profession – BEM, IEM, CIDB, PWD, MQA, MOSTI and MOHE. I am also grateful for the opportunities given by ICP Sdn. Bhd, the Center of Excellence for Concrete and King Saud University for giving me the opportunity to do research in their respective labs and their research grants.

My parents (*Alfatihah*) have been my inspiration for their love and courage to bring up 18 children in a home full of laughter and care. I am truly grateful to all my family members who have given me encouragement and support. My life would not be complete and meaningful without my wife and children. I am blessed with their understanding and love. If what I have today is a success, it is clearly not mine alone but belongs to all of you.

"Who created you, fashioned you perfectly, and gave you due proportion"

[Infitar 82:7]

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3. Prof. Dr. Abdul Rahman Abdul Razak
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