Chapter 36
Development of Green Concrete from Agricultural and Construction Waste

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36.1 Introduction

In the 11th Malaysia Plan (Economic Planning Unit 2015), the Malaysian construction industry has been urged to change from the conventional construction method to Industrialised Building System (IBS) to attain better construction quality and productivity. The use of IBS has been made compulsory in the construction of public buildings, and the adoption of this alternative construction system was fully supported by the government through programmes, incentives and encouragement policies stipulated under the IBS Roadmap 2011–2015 (CIDB 2010). Through the recently launched Construction Industry Transformation Plan 2016–2020 (CIDB 2015), see Fig. 36.1, the government, together with the Construction Industry Development Board (CIDB), will be emphasizing on a construction system which is environmentally sustainable, in line with the requirements of green construction and the reduction of carbon emission of CO_2.

It has been well documented that the global expansion of the greenhouse effect has been partly due to the production of cement. It was approximated that 2.7 billion cubic metres of concrete were consumed with production spread unevenly among more than 150 countries. This equals more than 0.4 m^3 of concrete consumed per person annually. The production of Portland cement, an essential constituent of concrete, leads to the release of a significant amount of CO_2 and other gases leading to the effect on global warming. Literature has proven that the manufacturing of 1 ton of Portland cement produces about 1 ton of CO_2. Since the production of Portland cement is not particularly environmentally friendly and the

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A. Sayigh (ed.), *Transition Towards 100% Renewable Energy*,
Innovative Renewable Energy, https://doi.org/10.1007/978-3-319-69844-1_36

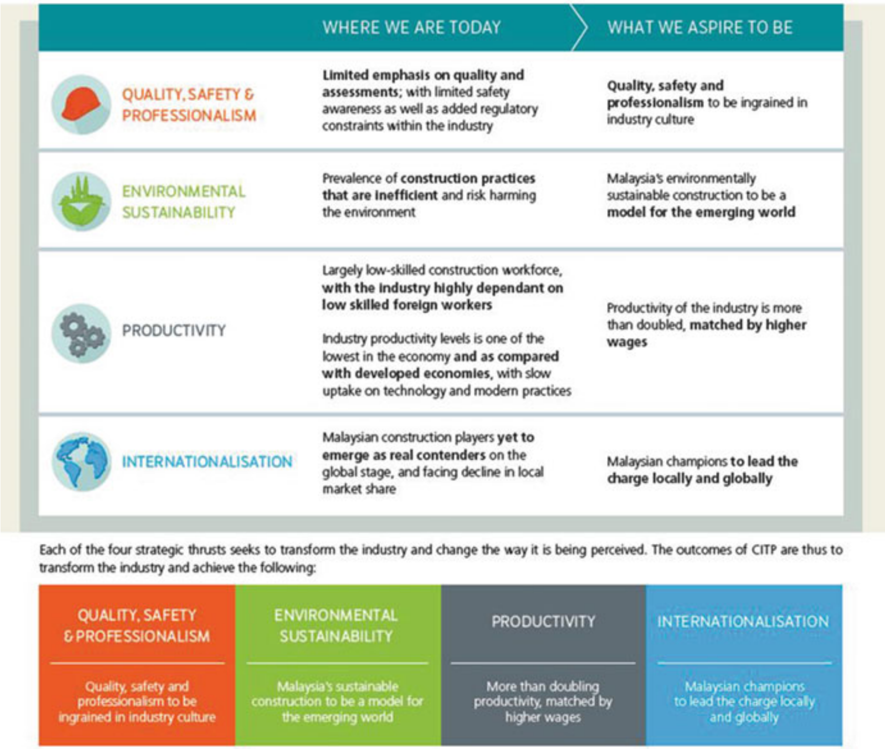


Fig. 36.1 Construction Industry Transformation Plan (CITP) 2016–2020 (CIDB 2015)

impact it causes to the environment due to carbon emission (CO_2) calls for the development of the innovative green concrete which utilizes agricultural and construction waste as cement replacement and the reduction of natural resources (Vlastimir et al. 2013; Megat Johari et al. 2011; Karim et al. 2011). The challenge for green concrete is therefore to use as little Portland cement as possible and replace the Portland cement with supplementary cementitious materials such as agricultural waste and waste from construction such as recycled concrete aggregates (Meyer 2009). The consumption of agricultural and construction waste in green concrete reduces the dependency of earth natural resources, reduces waste and improves the environment and quality of life. Hence, the design of green concrete as a sustainable building material is an innovative idea and has attracted the attention of many researchers and construction players around the world.

However, literature has shown lack of evidence on investigations related to the combination of the four waste materials (POFA, RHA, POF and RA) into one mix design. This causes a deficiency in the material and mechanical properties of the proposed green concrete comprising of the four components from agricultural and construction waste. Due to the high composition of waste material in the green concrete mix, it is expected that a severe non-homogeneous and anisotropic material would be produced and an effect to its strength and mechanical properties of the proposed green concrete is anticipated. Nevertheless, the paper attempts to understand and clarify the influence and performance of concrete with waste materials and its additives. Hence, a discussion on past and present development of green concrete including its characteristic strength properties compared to normal concrete is presented.

36.2 Green Concrete

Malaysia is one of the largest producers of palm oil fuel ash (POFA) in the world. This is apparent when 1000 tons of POFA were produced annually by 200 numbers of palm oil mills in operation. Figure 36.2 shows the production of palm oil producers around the world as recorded by Zeyad et al. (2017). These POFA if not utilized will be dumped into ponds as agricultural waste products. It has also been documented that approximately 110 million tons of rice husk and 16–22 million tons of rice husk ash (RHA) are generated worldwide. Figure 36.3 shows an example of a palm oil tree, its fruit bunches and fibres (from palm oil shells). Until today, no proper utilization of POFA and RHA has been developed and adopted in the construction industry around the world (Payam et al. 2014). However, as issues on sustainable construction gain more prominence, research on green concrete using agricultural by-product waste such as POFA and RHA and construction waste (recycled concrete aggregate) have been conducted and were given serious considerable work by researchers from Malaysia and other parts of the world.

The outcome of the research shows that the addition of agricultural waste or construction waste with additives for green concrete shows positive and satisfactory strength when compared to normal concrete. Palm oil fuel ash (POFA) and rice husk ash (RHA) are an agricultural waste containing large components of silica and have been accepted as a pozzolanic material in concrete for the past 20 years. The utilization of POFA or RHA as a pozzolanic material to partially replace Portland cement has been extensively investigated. However, the authors observe that a

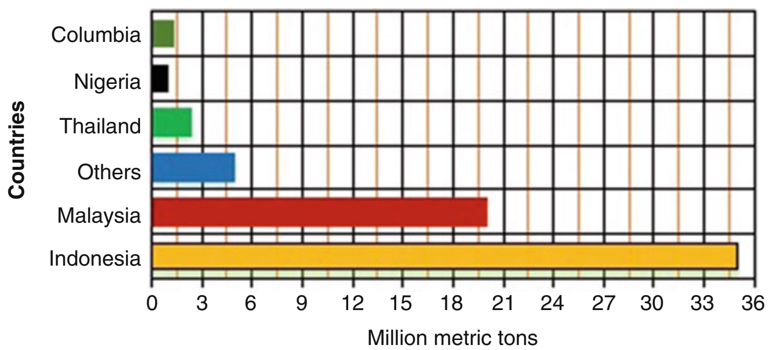


Fig. 36.2 Palm oil producer countries (Zeyad et al. 2016)

Fig. 36.3 Palm oil tree, fruit bunch and fibrous strands (Mohamed and Huzaifa 2008)

combination of both POFA and RHA in concrete has not been fully investigated and has yet to be fully accepted and officiated by the construction industry in Malaysia and neighbouring countries.

Likewise, research have shown that using natural palm oil fibre (POF) at 0.1–0.5% by percentage weight of cement enhances the strength of concrete by more than 40% from normal concrete. It is interesting to note that from research observation, the palm oil fibres tend to create an uneven distribution causing a balling-like effect to occur in the concrete.

Concrete also consumes large volume of natural aggregates (sand and gravel) as a key component of its material matrix. This raises concerns about the preservation of the earth natural resources. Hence, researchers have studied the cause and effect of this issue and recommended ways to balance the shortfall of future natural resources. One of the solutions to this is the recycling of demolished concrete structures to produce new structural concrete elements. Studies have shown that recycled concrete aggregate (RCA) is a viable option for a construction's material in terms of its mechanical properties and structural behaviour. Therefore, the successful use of agricultural and construction waste contributes to energy saving and conservation and preservation of natural resources and reduces rising construction cost. Producing green concrete is sustainable as it solves the disposal of waste and protects the environment.

36.3 Influence of Palm Oil Fuel Ash (POFA) on Strength of Concrete

Research on utilizing POFA as cement replacement has been conducted for the past two decades. POFA essentially contains siliceous compositions and reacts as pozzolans to produce a cement-like reaction to form a concrete. Table 36.1 shows

Table 36.1 Research on green concrete with POFA

Concrete properties	Researchers								
	Altwair et al. (2012) [1]	Altwair et al. (2012) [2]	Altwair et al. (2012) [3]	Tangchirapat et al. (2009)	Islam et al. (2016) [1]	Islam et al. (2016) [2]	Awal and Abubakar (2011) [1]	Awal and Abubakar (2011) [2]	Awal and Abubakar (2011) [3]
Ratio water/binder	0.30	0.36	0.38	0.32	0.30	0.40	0.48	0.42	0.38
Median particle size of POFA d_{50} (μm)	Ground 2.87	Ground 2.87	Ground 2.87	10.10	17.10	17.10	14.58	14.58	14.58
Fibre	Polyvinyl alcohol fibre 0.02			–	–	–	–	–	–
Superplasticizer	0.001	0.001	0.001	0.064–0.116	0.34–0.062	0.00–0.062	–	0.02	0.02

( ) Types of concrete mix design

a summary of various concrete mix designs with POFA as a cement replacement from various researchers (Islam et al. 2016; Altwair et al. 2012; Awal and Abubakar 2011; Tangchirapat et al. 2009). Figure 36.4 clearly illustrates the differences in compressive strength of concrete from various ratios of POFA as cement (ordinary Portland cement) replacement. Interestingly, the results show that the concrete compressive strength reduces as ratio of POFA increases. Tangchirapat et al. (2009) recorded the highest result of compressive strength ranging from 59 to 61 MPa compared to others. In his experimental work, POFA was initially grounded, and high fineness of POFA was produced with a median particle size d_{50} of 10.1 μm; this size was more subtle than the typical OPC type I cement which measures at approximately 14.6 μm. The degree of fineness of POFA shows significant influence to concrete strength properties (Tangchirapat and Jaturapitakkul 2010). The specific gravity of POFA and its shapes has also been observed to affect its water requirement further influencing the workability and strength (Chindaprasirt et al. 2007). However, the particle size of POFA by Altwair et al. (2012) was the most subtle (see Table 36.1; Fig. 36.4), but results clearly show lower strength of concrete was achieved compared to Tangchirapat et al. (2009). Other variable that may have influenced the strength of concrete was the use of superplasticizer which affected its workability and eventually its strength.

This observation highlights the influence of POFA in concrete which shows an obvious increase in its strength. Research by Altwair et al. (2012) replaces cement by 40% POFA (POFA/OPC = 0.4) by mass which recorded an increment in strength of 10.3% from normal concrete. POFA/OPC = 0.2 or 20% POFA replacement was conducted by Tangchirapat et al. (2009) which resulted in a 24% increase in strength compared to normal concrete. Meanwhile, research by Islam et al. (2016) with 10% POFA as OPC replacement observed an increase in concrete strength by 11%. However, when POFA exceeded 40% as cement replacement,

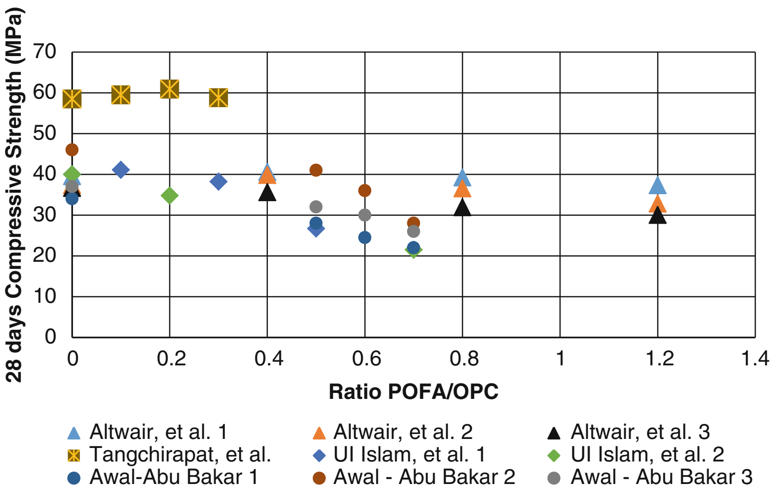


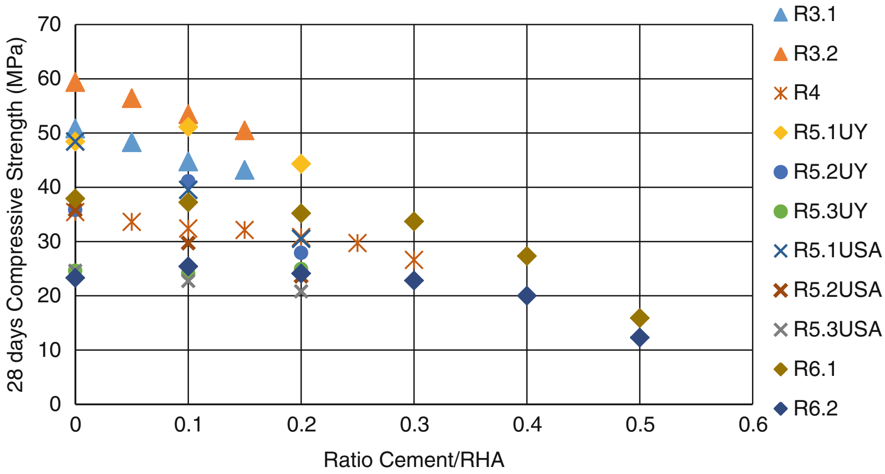
Fig. 36.4 Compressive strength of green concrete with different ratios of POFA/OPC

Awal and Abubakar (2011) show a substantial decrement to the strength of concrete.

36.4 Influence of Rice Husk Ash (RHA) on Strength of Concrete

In the 1970s, production of RHA was not a popular study for research when the uncontrolled combustion of RHA was found to have poor pozzolanic properties. However, Mehta (2001) described an investigation on the pyro-processing parameters on the pozzolanic reactivity of RHA, and the high reactive RHA was then obtained. Since then, RHA has been used as an alternative for active silica production to be used as cement concrete replacement in the construction and building industry (Della et al. 2002; Ganesan et al. 2008).

Figure 36.5 shows the concrete compressive strength distribution with different ratios of RHA as cement replacement. Unfortunately, it has been generally observed that by adding RHA as cement replacement, a reduction in its strength was evident. Kishore et al. (2011) conducted test on RHA from 0%, 5%, 10% and 15% cement replacement with two target concrete strengths at M40 and M50. Kishore observed that adding RHA (as cement replacement) reduces its compressive strength, but a higher target strength of 3% and 8% for grades M40 and M50 was recorded, respectively. Madandoust et al. (2011) tested concrete with up to



Note: R3.1, R3.2 - Kishore et al. (2011); R4 - Madandoust et al. (2011); R5.1UY - R5.3UY & R5.1USA - R5.3USA - Rodríguez (2006); R6.1, R6.2 -Al-Khalaf & Yousif (1984)

Fig. 36.5 Compressive strength of green concrete containing various percentages of RHA. Note: R3.1 and R3.2, Kishore et al. (2011); R4, Madandoust et al. (2011); R5.1UY–R5.3UY and R5.1USA–R5.3USA, Rodríguez (2006); R6.1 and R6.2, Al-Khalaf and Yousif (1984)

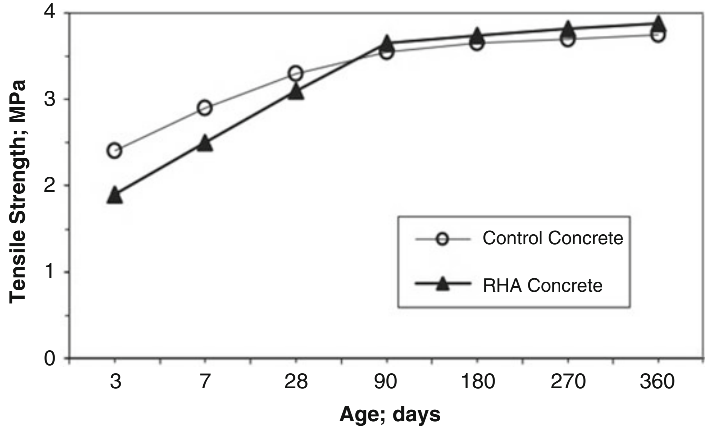


Fig. 36.6 Tensile strength with age (Madandoust et al. 2011)

30% RHA as cement replacement, and a reduction in strength was again observed from 38 MPa at 0% RHA reducing to 28 MPa at 30% RHA. By further observation of Madandoust's work, a 5% RHA cement replacement is shown to be ideal.

Rodriguez (2006) also conducted research on concrete with RHA at 0%, 10% and 20% cement replacement. However, the research observed that replacing cement with 10% RHA recorded higher compressive strength by 4%. Yet, similar trends (as observed by Madandoust et al. 2011) occur when higher percentage of RHA shows a reduction of strength by 6% compared to normal concrete. A high volume of RHA as cement replacement of up to 50% was conducted by Al-Khalaf and Yousif (1984). Results show that the strength of concrete containing 50% RHA produces the lowest strength with a reduction of 60% from normal concrete. However, concrete containing 10% and 20% of RHA achieved higher strength by 9% and 3% compared to normal concrete.

A long-term study on the tensile strength of concrete was conducted by Madandoust et al. (2011). Figure 36.6 shows clearly the tensile behaviour of normal concrete with respect to concrete with RHA. The figure shows that when concrete with RHA reached 90 days, higher tensile strength values were achieved than normal concrete. This trend indicates that the hardening process of concrete with RHA was still progressing beyond 90 days (similar to normal concrete). This hardening process sustained its behaviour even at 360 days.

36.5 Influence of Palm Oil Fibre (POF) to Strength of Concrete

Ahmad et al. (2010) reported that the addition of palm oil fibres will enhance the mechanical properties of concrete especially its fatigue and tensile stresses as well as cracking and impact resistance. It has also been reported that adding POF also

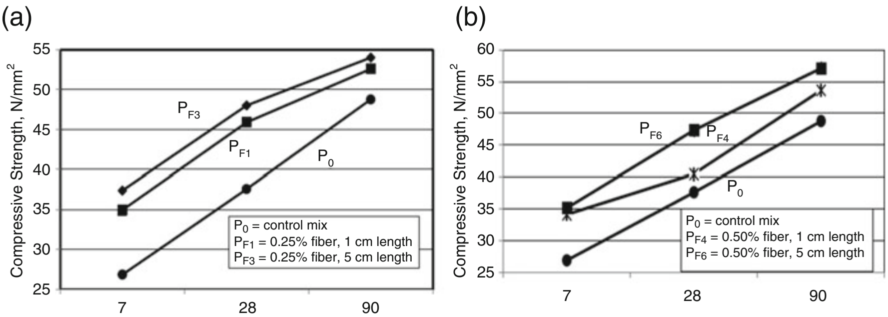


Fig. 36.7 Compressive strength of concrete with different percentages and lengths of POF (Mohamed et al. 2008). (**a**) 0.25% POF with 1 cm and 5 cm length. (**b**) 0.5% POF with 1 cm and 5 cm length

increases its flexural strength. POF with length from 1 cm up to 5 cm, and initially immersed in water, was observed to be applicable for concrete. However, as the length of POF exceeds 5 cm, a balling effect in the concrete will occur to the POF which causes the fibres to be less active. The effective fibre content used was observed to fall within 0.1–0.2% of cement by weight; however, by the addition of 1% of fibre, the concrete will not achieve its desired strength. Interestingly, research by Mohamed et al. (2008) observed that concrete with 0.25% fibre content and 5 cm fibre length shows an enhanced compressive strength compared to normal concrete (see Fig. 36.7).

36.6 Influence of Recycled Concrete Aggregate (RCA) to Strength of Concrete

The major benefits of using recycled concrete aggregate in new construction include lower environmental pollution, reduction in the need for valuable landfill space and conservation of resources for natural aggregates. Furthermore, the application of recycled concrete aggregate (RCA) in concrete is expected to contribute economically and is environmentally viable. However, RCA obtained from crushing from old concrete can exhibit inconsistent properties depending on the composition, particularly the water-to-cement (W/C) ratio and cement content of the original concrete. The quality of RCA is generally inferior to that of normal aggregate. Alengaram et al. (2011) have used 0%, 30%, 50%, 70% and 100% RCA in their study. The researchers observed that the RCA replacement can produce high-workability concrete with higher compressive strength for 50% RCA. A compressive strength reduction was observed for percentage exceeding 50%. Figure 36.8 shows the compressive strength and flexural strength results of concrete using different ratios of RCA. However, the flexural strength of concrete shows a slight reduction (a maximum of just 5%) with different ratios of RCA.

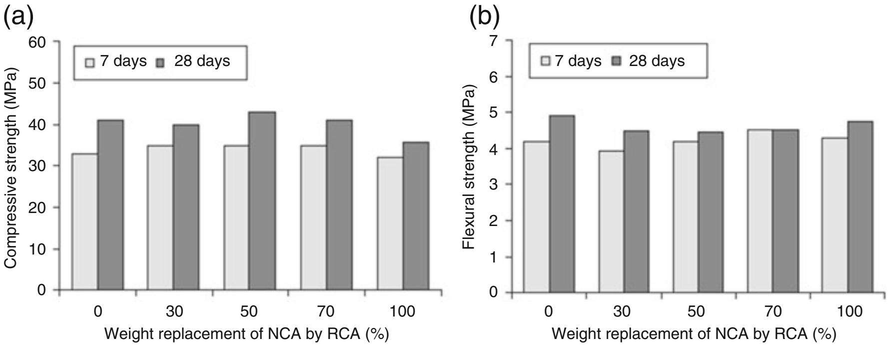


Fig. 36.8 Compressive strength and flexural strength of green concrete with different percentages of RCA (Alengaram et al. 2011). (**a**) Compressive strength. (**b**) Flexural strength

36.7 Conclusions

The need for going green is an essential element for producing an environmentally sustainable construction. Malaysia through its Construction Industry Transformation Plan (CITP) 2016–202 has laid its strategies in producing a construction system which is eco-friendly and environmentally sustainable. To ensure the success of this strategic plan, Jamilus Research Centre of Universiti Tun Hussein Onn Malaysia together with the University of Greenwich will be engaging in a research on green concrete utilizing agricultural and construction waste materials. Literature has shown that research on green concrete has been conducted for the past two decades worldwide. The utilization of agricultural waste with pozzolanic properties and construction waste shows an enhancement in the compressive and tensile strength of concrete. Further addition of palm oil fibres as binders essentially upgrades the concrete flexural strength and cracking properties. From observation of past and present research work, replacing cement with POFA and RHA by 20% and 10% enhances the concrete strength by up to 10%. Adding 0.1–0.2% of POF has also been recorded to have improved its strength and cracking properties of concrete with fibres not exceeding 5 cm long. Likewise, replacing natural aggregates with 50% RCA shows an improvement to its concrete compressive strength, but slight reduction in its flexural strength was observed.

Acknowledgement The authors acknowledge funding from the Fundamental Research Grant Scheme (FRGS) Vot. No. 1573, received from the Ministry of Higher Education of Malaysia. The first author also acknowledges the support received from Jamilus Research Centre, Universiti Tun Hussein Onn Malaysia, for the success of this research work.

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