Mechanical Properties and Sustainability of Palm Kernel Shell Powder (PKSP) as a Partial Replacement of Cement

Gunalan Vasudevan* and Maneswaran Subramaniam
Department of Construction Management, Faculty of Built Environment, Tunku Abdul Rahman University College Malaysia

*Email: gunalaanv@tarc.edu.my

Abstract. This research showed the results of experiments evaluating the use of palm kernel shell powder from palm oil refinery waste production as partial replacement of Ordinary Portland Cement (OPC). Many researchers have studied the use of agro-waste as constituents in concrete but not as a partial replacement of cement specifically. Therefore, the objective of this research is to identify the performance of palm kernel shell powder as partial replacement of cement in the production of concrete. Palm kernel shell powder in various amounts, namely 5%, 10%, 15% and 20% by volume was added as a replacement for Ordinary Portland Cement (OPC). The results showed that palm kernel shell powder concrete greatly improved the workability, compressive and flexural strength of concrete. All of the testing were followed the American Society for Testing and Materials (ASTM). The workability of concrete was tested by using slump test to check the consistency of freshly made concrete. For compressive strength, a total of 27 cubes with size 150mm x 150mm x 150mm were used to determine the compressive strength of concrete when replace with 5%, 10%, 15% and 20% of palm kernel shell powder as a replacement of cement in concrete. The results showed that palm kernel shell powder concrete greatly improved the compressive and flexural strength of concrete. The rate of water absorption of palm kernel shell powder reduced as palm kernel shell powder filled up the existing voids while making it impermeable. However, the compressive strength of the palm kernel shell powder decreases gradually when the amount increased. It can be concluded that the optimum amount of palm kernel shell powder as partial cement replacement is 15%. In the correction, an experimental investigation of ultrasonic pulse velocity (UPV), carbonation test and rebound hammer test was undertaken to palm kernel shell powder and admixtures as partial replacement cement in concrete.

Keyword: Palm kernel shell powder, admixture, and Mechanical Properties

1. Introduction
Sustainable development of construction industry should be carried out in order to protect the future generation. [1] By-products and agro-waste materials such as bottom ash, crushed concrete fines, filter residue, paper ash, palm kernel shell and lignite fly ash predicted to have potential for use in building materials, for instance as raw materials for clinker production, as supplementary cementitious materials (SCMs) or mineral additions in concrete. The properties of the products are dependent on the reactivity of the waste materials used, which can be classified as inert, latent hydraulic or pozzolanic. [2] In this study, waste materials were first characterised. This was followed by theoretical considerations of the mentioned application options.
Oil palm is genuinely a golden crop of Malaysia. Oil palm is developed for its oils. As vegetable oil seed crop, the oil palm is a proficient converter of sunlight based vitality into biomass. [3] Other than being a productive maker palm and kernel oil, it additionally creates various residues and by-products. The by-products of oil palm industry are from the field and factory. Palm kernel shells are one of the wastes from palm oil industry, which have for quite some time been utilized as fuel in boiler to create steam and power for plant forms [4]. Palm part shell is the hard shell of the oil palm organic product seed that is broken to take out the piece utilized for extricating palm oil. Thus, it is the by-products of palm oil processing during which the palm oil is extracted.

2. Problem Statement
First and foremost, it is expected that the usage of Ordinary Portland Cement (OPC) will be increased by 100 trillion tons by 2050 due to rising of infrastructural development all over the world. [5] Around 900 kg of CO$_2$ is released per ton of concrete conveyed by current practices. In like manner, the OPC is assessed to have contributed 5–7% of worldwide anthropogenic CO$_2$ emanations in 2009. [6] This carbon dioxide emission leads to one of the main cause of climate changes all over the world. For an example, acid rains will occur and it may make the infrastructure like buildings to deteriorate easily due to the chemical substances that form from carbon emission. [7] Therefore it is essential to find a solution to find a suitable material that can be replaced in the cement, so effect of carbon emissions can be reduced. Meanwhile, oil palm factories in Malaysia have continued extending as a result of the degrees of fame of human needs, for instance, vegetable oil. Palm kernel shell is one of wastes produce at oil palm industrial facilities. In Malaysia, in excess of 4 million tons of bit palm shell has been made yearly [8].

3. Methodology
In this research is to determine the performance of the concrete that contain the palm kernel shell powder by preparing concrete cube sample and tested to obtain some of the basic engineering properties. The concrete mix design is done by systematic analysis and chooses the proportion of the ingredient to use the concrete mix to produce an economical concrete and also with strength that desired when the cube is hardened. The variables which can be controlled are water cement ratio, maximum aggregate size, aggregate grading and use of admixture.

| Phase 1                  | To identify palm kernel shell powder as addition into concrete in percentage | Remarks                          |
|--------------------------|------------------------------------------------------------------------------|---------------------------------|
| Material Selection       | If no, back to material                                                      |                                  |
| Identify Tests/Experiment to be carried out |                                  |                                  |
| Analysis of Particle size distribution and Properties of palm kernel shell powder |                                  |                                  |

| Phase 2                  | Mixture of materials and percentage of palm kernel shell powder as addition | If no, back to analysis          |
|--------------------------|--------------------------------------------------------------------------|---------------------------------|
| Design and conduct       |                                                           |                                  |
| Mixing, casting, and compaction |                                                           |                                  |
| Dry Shrinkage Concrete   |                                                           |                                  |
| Testing of Hardened Samples |                                         |                                  |

| Phase 3                  |                                                                                     |
|--------------------------|---------------------------------------------------------------------------------------|


3

Long Term Behaviors

| Phase 4         | Durability Test |
|-----------------|-----------------|
| Performance     | Application (Brick interlocking) |

Figure 1. Conceptual framework

4. Result and Discussion

4.1. Workability

Figure 2 shows that the 20% complete replacement result is harsh which gave a shear slump. It is recorded very low slump (0–4 mm) meaning very low workability. Lightweight concrete of 15 N/mm² gave slump in the range of 0–260 mm. It can be said that concrete with low slump doesn’t necessarily denote high compressive strength; It was observed that slump value of 105 mm (high workability) was achieved with incorporation of small percentage of super plasticizer. Replacement of PKSP increases the slump remains a true slump which means the workability rate is high but when it increases to 20% the slump drops these is merely because the chemical properties of PKSP has overtaken the water/cement ratio rate when it loses the workability.

Figure 2. Slump test Different Percentages of palm kernel shell

4.2. Compressive Strength Test

Based on the Figure 3 compressive strength of all mixes increased steadily with respect to curing age. At 5% partial replacement of cement, compressive strength of concrete specimen was 26.41 MPa, 29.33 MPa and 30.21 MPa according to their age of curing days which is 7 days, 14 days and 28 days. While that of 20% were very low compared to the former results.

Figure 3. Compressive strength test
It undergoes deterioration at 20% replacement of PKSP most probably because of bond between particles is to a large extent dependent on surface texture, cement paste bonds more adequately with rough surface. Surface area of contact between the palm kernel shells is increased as the percentage of palm kernel replacement increases. Since the content of cement in the concrete remained constant, the needed extra bonding was lacking leading to reduction in compressive strength. So at 15% of replacement, its shows a great compressive strength.

4.3. Ultrasonic pulse velocity (UPV)

Table 1. Results of UPV with varying % replacement of PKSP

| UPV, Direct Method | 0%   | 5%   | 10%  | 15%  | 20%  |
|-------------------|------|------|------|------|------|
| 7 Days            | 3.412| 4.171| 4.678| 4.717| 4.212|
| 14 Days           | 3.563| 4.493| 4.671| 4.807| 4.314|
| 28 Days           | 3.745| 4.610| 4.967| 4.912| 4.414|

Based on the Table 1, UPV test shows very excellent trend lines when percentage replacement of PKSP increase from 5% to 15% where the concrete quality shows good strength compared to percentage replacement of 20%. This is because at 20% of PKSP replacement, the concrete may have loss its strength maybe because there is more moisture content of concrete which leads to more porosity in the concrete which finally makes the concrete weaken with high percentage of PKSP replacement. In conclusion, higher velocities indicate good quality and continuity of the material which also means the PKSP replacement showing great improvement within the casted concrete in between 5% to 15%.

4.4. Flexural strength test

The test results are presented in Table 2 the flexural strength values of concrete with palm kernel shell ash (PKSP) when compare with the control concrete were increased by 5% to 20%. The flexural strength at 5% of partial replacement of PKSP was 2.7 MPa, 2.9 MPa and 3.0 MPa for 7, 14 and 28 days. Increases of 15% in flexural strength value of concrete contain PKSP was observed when compare with the control mix. Flexural tensile strength was increased with age which means PKSP having a good impact on the strength of concrete. Flexural tensile strength was reduced with increase in 20% of PKSP replacement according to the data and this is possibly because of moisture condition of the concrete specimen.

Table 2. Results of compressive strength test with varying % replacement of PKSP

| Flexural Strength, MPa | 0%   | 5%   | 10%  | 15%  | 20%  |
|-----------------------|------|------|------|------|------|
| 7 days                | 2.1  | 2.7  | 2.9  | 3    | 2.6  |
| 14 days               | 2.4  | 2.9  | 3    | 3.1  | 2.7  |
| 28 days               | 2.6  | 3    | 3.10 | 3.2  | 2.8  |

4.5. Rebound Hammer Concrete Test

According to Figure 4 above rebound hammer test shows strength increasing trend lines where percentage replacement of PKSP increase from 5% to 15% where the concrete quality shows good strength compared to percentage replacement of 20%. This is because at 20% of PKSP replacement, the concrete may have started to loss its strength maybe because the surface and moisture condition of the concrete which finally makes the concrete weaken with high percentage of PKSP replacement. These moisture content could be adapted from the PKSP and surrounding due to age of concrete exposed to outside condition. In conclusion, uniformity of the concrete of concrete is greatly increase when the the optimum percentage reached which is 15%.
4.6. Microstructures of Palm Kernel Shell Powder
The apparent morphologies of the Palm Kernel Shell Powder examined by SEM are shown in Figure 5(a) it was observed that C-S-H gel was vastly spread on the mixture of hydrated cement paste which was the main cause for the effective strength. Formation of Portlandite Ca(OH)₂ and Calcite (CaCO₃) was visualized all over the exterior surface of hydrated cement paste. These expansion and distribution of mineral elements was one of the reasons for the effective strength of the mix. Replacement of fine aggregate with manufactured sand did not expose any flaw in strength but, the range of distribution of minerals was changed due to replacement of fine aggregate with manufactured sand. The SEM image in Figure 5(b) SEM micrograph of the harden cement paste, the distribution of C-S-H was nearly decrease at stage of 28 days due to replacement of cement with PKSP. In this mix, the range of development of C-S-H was less which may be due to unreacted particles present in the mix.[9]

4.7. FTIR spectra and TGA analysis
Based on the results from Figure 5(a) IR spectra palm kernel shell powder was determined by transform infrared (FTIR) spectrometry of treated palm kernel shell powder respectively. The presence of characteristic band of -O-N = N- group at 1,031.8 cm⁻¹ and C-O stretching at the region of 1,300 to 1,000 cm⁻¹. Figure 5(b) shows result from TGA showed that there were two stages of weight losses. For the first stage, minor weight loss occurred at temperature below 200 °C - 500°C attributed to an adsorption of water molecules to the surface of the material and loss of organic compound.
5. Conclusion and Recommendation

The overall objective of the work was to investigate the feasibility of palm kernel shell powder as a partial replacement of cement to concrete mix. This study included the preparation of concrete mixes containing and the evaluation of palm kernel shell powder concrete properties in fresh and hardened states. The studying properties involved mix workability, compressive strength and flexural strength. According to experimental results, the usage of palm kernel shell powder concrete mixes as an alternative of disposal for palm kernel shell powder is possible. The current type of palm kernel shell powder accumulated in dumping sites and the expected future type were used in making concrete mixes. The influence of both types on concrete properties was studied. In all cases there was an optimum quantity of palm kernel shell powder which can be used without introducing any change in mix preparation and acceptable properties were still be produced [10]. The study showed that the palm kernel shell powder can be used in production of cement without changing the normal industrial process.

Recommendation for further research

The following recommendations are proposed for further research and study in order to form a complete picture of using palm kernel shell powder in concrete mixes:

1) Investigation is needed on the different superplasticizer used together with palm kernel shell powder in the concrete mix design.
2) Study is required for palm kernel shell powder mix with other by-products in the concrete mix design.
3) Further investigation of the higher percentage of replacement of the cement by the palm kernel shell powder in concrete mix design.
4) Longer curing time is required in order to understand the behaviour of the concrete, and it might be giving the different result for oil palm fibre concrete.
5) Durability test such as sulphate attack test must be further study in order to understand percentage loss in weight of the palm kernel shell powder concrete by sulphate attack

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