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Investigation on Sawdust and Palm Kernel Shells as Partial Replacement for fine and Coarse Aggregate in Concrete Production

Nwaobakata, C[a], Eme, D.B[b] ,
[a,b]Civil Engineering department, University of port Harcourt, Rivers state, Nigeria
Corresponding Author: Nwaobakata, C

Abstract: The high and rising cost of construction in developing countries, especially Nigeria has been a major concern to government and private developers. This study investigated the partial replacement of Saw Dust (SD) and Palm Kernel Shell (PKS) for fine and coarse aggregate respectively in concrete production. The materials were dried for some days, crushed, sieved and batched by volume. Using a design mix of 1:2:4, with a water cement ratio of 0.6, the prepared specimens were poured in cube moulds of 150x150x150mm, cured by immersion in water for different time durations (7, 14,21and 28 days). The results showed that workability (slump) reduces as the percentage of SD and PKS increases. It further revealed that the compressive strength reduced with increase in SD and PKS. However, compressive strength from 0-15% of SD and PKS addition meets the criterion for light weight concrete. The models developed from the study correlated well with experimental values as high coefficient of determination value were obtained. The models can thus, be satisfactorily used to predict the compressive strength of Saw-Dust-Palm Kernel Shell concrete. From analysis of this study, Sawdust and Palm Kernel Shell can be used to replace fine and coarse aggregate in light weight pavement construction accommodating less traffic.

Keywords: Palm Kernel Shell, Sawdust, Slump, Compressive Strength

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I. INTRODUCTION

Road surface or pavement is the durable surface material laid down in an area intended to sustain vehicular or foot traffic, which may be flexible or rigid. Rigid pavement, otherwise called concrete pavement is constructed from cement concrete which is basically composed of cement, aggregates and water. The quality of concrete produced at the end of the day is a function of the quality of the individual components, the mix design and the curing method and period adopted.

Over the years, the financial implications involved in rigid pavement construction has always been a major cause for concern and thus any reasonable practice to reduce the overall cost of construction is always encouraged. The cost of construction can be reduced through the careful replacement of constituent elements without adverse effect on the strength of concrete produced.

The discharge of wastes into the environment is a direct consequence of the industrialization procedures adopted by a nation. These problems are eating deep into our nation, Nigeria and therefore measures to mitigate against these problems are always welcomed and encouraged as the cost of construction would be reduced and also the environmental conditions of the society reserved. Some of these wastes can be utilized in the construction industry. This work investigates the effect of usage of Saw-Dust (SD) and Palm Kernel Shell (PKS) in concrete production.

Saw-dust is a by-product obtained from sawmills during wood conversion and processing. Researchers, have studied the potential of using waste sawdust in concrete production. Yong et al., (2013) in their study revealed that at 5% level of sawdust replacement, the compressive strength of concrete met the C25 grade. Raheem et al. (2012) also investigated the use of sawdust ash (SDA) in the partial replacement for cement in concrete and obtained an optimum compressive strength value of 23.26N/mm^2 at 90 days for 5% SDA replacement.

Palm Kernel Shell (PKS) is a waste material obtained during the crushing of palm nuts in the palm oil mills for palm oil extraction with proper mix design, PKS can be utilized to develop normal strength concrete which ranges from 20 to 30 (MPa) (Shafigh et al. 2011).Alengtaram et al., (2013) from their study discovered that PKS can be used as lightweight aggregate in production of lightweight concrete. Imam et al., (2004) also discovered that palm nut shell can be used as construction material in low cost buildings since it attained a compressive strength of 18N/mm^2. Zarima et al. (2016) also from their research on the use of PKS as a replacement for coarse aggregate in light weight concrete discovered improvement of concrete properties like workability water absorption and compressive strength.

This paper therefore considered a possible way of using these by products along side each other in concrete production. This would go a long way to reducing the enormousamount of wastes generated and also help in reduction of the huge financial implications of rigid pavement construction.

II. MATERIALS APPARATUS AND METHODS

2.1 Materials and Preparation Procedure:

Sawdust or wood dust used for this study was sourced from a local sawmill in Port Harcourt, Rivers State. The obtained saw-dust was dried for several days, filtered to remove unwanted substances and was subjected to sieve analysis with the used portion been that portionfiner than sieve No.200.

The Palm Kernel shell (PKS) was sourced from an oil mill, located in Port Harcourt. The PKS was dried for several days and crushed into smaller particles. The portion retained between 4.75mm and 13mm sieve was used for coarse aggregate replacement.

The granite was crushed stone sourced from a construction site in the University of Port Harcourt Environment. The crushed stone was used as coarse aggregate. This crushed stone was subjected to sieve analysis and the portion passing through the 13mm sieve and retained on 4.75mm sieve was used for this study. This is done to ensure uniformity of aggregate with those of PKS.

The cement used for this study was the Dangote brand (R.425,CB4227) obtained from a local shop in Port Harcourt.

The fine aggregate used was fine rivers sand sourced from a site in the University of Port Harcourt environment. The sourced sand was sieved and discovered to be of zone 2 class.

2.2 Equipment and Apparatus

i. Compressive Strength Machine (Model 4207D, Chandler Eng USA) which meets the requirements of BS 1881:115 (1983)
ii. Slump cone (Model HM-40, Gilson Company, USA) which meets the requirements of BS 1882-102 (1983)
iii. 150mm x150mm x150mm steel moulds
iv. Other apparatus are: tag sieves, sensitive weighing instrument, curing tank, electric concrete mixer steel rod and trowel.

2.3 Methodology

2.3.1 Experimental Design

This study involved experimental tests, workability and compressive strength tests, on concrete specimen using saw dust as partial replacement for fine aggregate and palm kernel shell as partial replacement for coarse aggregate in concrete production for rigid pavements. The coarse aggregate sizes used here ranges from 5mm to 12.5mm. This partial replacement was done at 0%-40%, in 5% increments by volume of fine aggregate and coarse aggregate. A concrete design mix of 1.2.4 was adopted with a constant water-cement ratio of 0.6

2.3.2 Concrete Batching, Mixing and Curing

The batching by volume method was adopted here as the SD and PKS partially replace the fine and coarse aggregates respectively. The coarse aggregate, PKS, fine aggregate, SD and cement after correct proportioning using 1:2:4 design mix were thoroughly mixed together with the electric concrete mixer, before addition of water at 0.6 water-cement ratio. The aggregates were prepared in accordance to the requirements of BS 1017; Part 1 and 2 (1983). The constituents were mixed until an even paste was obtained. The concrete specimen produced were subjected to slump test for workability determination. After which they were cured for 7, 14, 21 and 28 days by total immersion in water for the determination of the compressive strength.

2.3.3 Workability or Slump Test

The workability of the fresh concrete was determined using the slump cone procedure as outlined below:
The slump cone was filled in three layers with each layer compacted for 25 blows using a steel rod.
The surface of slump cone was then leveled and allowed for 2 minutes.
The slump cone was then lifted off the concrete, thus allowing the pile of unsupported concrete to collapse.
The difference between the initial and final height of concrete was then recorded as the slump.

2.3.4 Compressive Strength Test

After the slump test, the fresh concrete specimen were transferred to the steel moulds and compacted using a steel rod for 35 blows. The concrete cubes were left for a 24 hours in the laboratory to set. They were then demoulded and taken to the curing tank, where they were completely immersed in water and cured for 7, 14 and 28 days. After which, the compressive strength was determined using the compressive strength machine (model 4207D, Chandler Eng, USA). The load at which the specimen failed was recorded and compressive strength calculated using Equation (1).

$$f_c = \frac{P_f}{A_c} \quad (1)$$

Where: f_c= Compressive strength at failure
P_f= Load at failure
A_c= Cross sectional Area of cube

2.3.5 Model Development

The Newton Divided Difference method is adopted in the formulation of the model properties assuming a third order polynomial of the form indicated in Equation (2).

$$P_3(x) = f(x_o) + f(x_o, x_1)(x-x_o) + f(x_o, x_1, x_2)(x-x_o)(x-x_1) + f(x_o, x_1, x_2, x_3)(x-x_o)(x-x_1)(x-x_2) \quad (2)$$

Where: x = percentage by volume replacement of by product
$F(x_1)$ = concrete property

The algorithm approach postulated by Oko (2008). Was adopted and followed in determination of model coefficients the basic assumption made here in this model formulation was that the percentage replacement offine aggregate with SD must be equal to the percentage replacement of coarse aggregate with PKS

III. RESULTS AND DISCUSSION

3.1 Workability/Slump

The slump test result obtained in this research study after partial replacement of aggregate with SD and PKS is hereby presented as shown in Table 1.

Table 1. Slump of SD-PKS fresh concrete:

%SD	% PKS	SLUMP (MM)		
		A	B	AV.
0	0	80.00	80.00	80.00
5	5	78.00	79.00	78.50
10	10	75.00	77.00	76.00
15	15	65.00	68.00	66.50
20	20	60.00	64.00	62.00
25	25	50.00	48.00	49.00
30	30	41.00	41.00	41.00
35	35	33.00	34.00	33.50
40	40	25.00	27.00	26.00

The result above showed that the workability of SD-PKS aggregate fresh concrete reduces as the concentration of SD and PKS increases with a sharp reduction noticed at 25%. Addition of SD and PKS. This reduction can be attributed to the density of SD and PKS been lower than that of sand and granite respectively. This is further clearly represented in Figure 1.

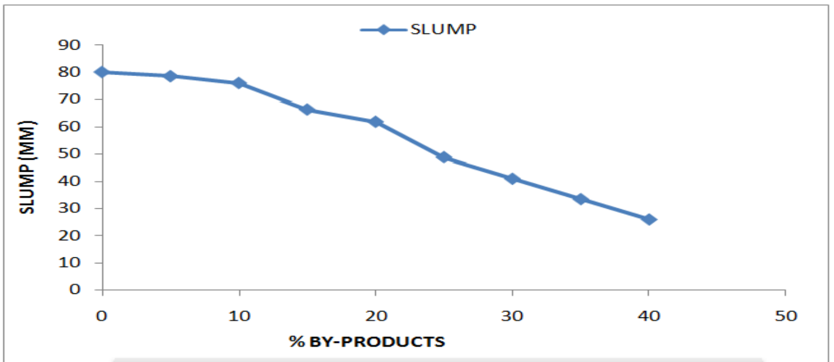

FIG.1. SLUMP VS % BY-PRODUCTS(SD & PKS)

3.2 Compressive Strength

The compressive strength result for 7, 14, 21 and 28 days SD-PKS aggregate concrete is presented here as shown in Table 2.

Table 2. Compressive strength of SD-PKS Aggregate Concrete

%SD	%PKS	COMPRESSIVE STRENGTH (N/MM²)											
		7 DAYS			14 DAYS			21 DAYS			28 DAYS		
		(1)	(2)	Mean	(1)	(2)	mean	(1)	(2)	Mean	(1)	(2)	Mean
0	0	9.95	9.75	9.85	12.50	12.00	12.25	16.60	16.70	16.70	20.00	20.10	20.05
5	5	9.00	9.50	9.25	12.00	11.90	11.95	16.10	16.50	16.30	19.60	19.70	19.65
10	10	9.00	8.90	8.95	11.40	11.70	11.55	16.00	16.00	16.00	19.95	19.25	19.20
15	15	8.20	8.40	8.30	11.00	10.90	10.95	15.10	15.50	15.30	18.00	18.80	18.40
20	20	7.90	8.00	7.95	10.00	10.50	10.25	14.00	14.20	14.10	15.60	15.70	15.65
25	25	7.85	7.45	7.65	10.05	9.95	10.00	13.15	13.25	13.20	15.00	15.10	15.05
30	30	7.15	7.75	7.45	9.70	10.00	9.85	12.40	12.60	12.50	14.45	14.65	14.55
35	35	7.00	6.90	6.95	9.40	8.90	9.15	12.00	11.80	11.90	14.10	14.00	14.05
40	40	5.90	6.20	6.05	8.70	9.00	8.85	11.35	11.20	11.25	13.70	14.00	13.85

The compressive strength of SD-PKS concrete reduces as the by products concentration increases (table 2, figure, 2) for 28th days compressive strength, the mean compressive strength reduces steadily from 20.05N/mm² (0% by products) to 17.65N/mm² (15% by products). Above the 15% by product addition, the mean compressive strength decreases drastically or sharply to 15.65N/mm² (20% by products addition). This is clearly represented as shown in Figure 2.

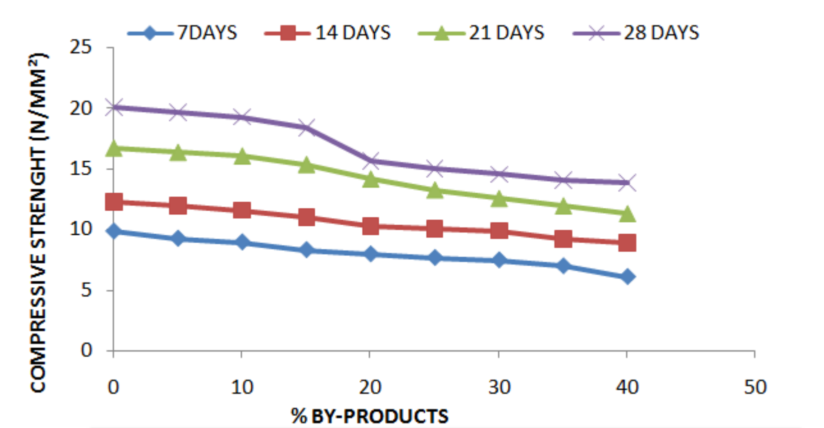

FIG.2. COMPRESSIVE STRENGTH VS % BY-PRODUCTS(SD & PKS)

Although the compressive strength reduces as by product concentration increases, the compressive strength obtained to 15% by products addition meets the criterion for light weight concrete as they have mean compressive strength value above 17N/mm² (NRNCA, 2017). The reduction in compressive strength may be attributed to the smooth and nature of PKS, thereby making it difficult to bind well with cement upon hardening.

3.3 EFFECT OF AGEING

The effect of SD-PKS concentration on the ageing of SD-PKS aggregate concrete is presented in Table 3 and Figure 3.

Table 3. Percentage Decrease in Strength and Age of concrete

AGE	MEAN COMPRESSIVE STRENGTH (N/mm^2)								
(Days)	Control 0	5%	%decrease	10%	%decrease	15%	%decrease	20%	%decrease
7	9.85	9.25	6.09	8.95	9.14	8.30	15.74	7.95	19.29
14	12.25	11.95	2.45	11.55	5.71	10.95	10.61	10.25	16.33
21	16.65	16.30	2.10	16.00	3.90	15.30	8.11	14.10	15.32
28	20.05	19.65	2.00	19.25	4.00	18.40	8.23	15.65	21.95

The compressive strength decrement of the SD-PKS concrete speeimen with age of concrete follows a linear trend (Figure 3). The decrement reduces as the age of concrete increases. The percentage decrement approaches a constant value as the concrete ages (Figure 3). This implies that there will be a time within the concrete lifespan when the value of compressive strength would be equal for both the control specimen (0% by-product) and the SD-PKS concrete but this would happen from 5% to 15% by-products addition. For percentage addition of by-products above 15% there is a sudden increase in percentage strength decrement (20%) signifying that percentage replacement of by-products should not be considered above the 15% concentration addition of by products.

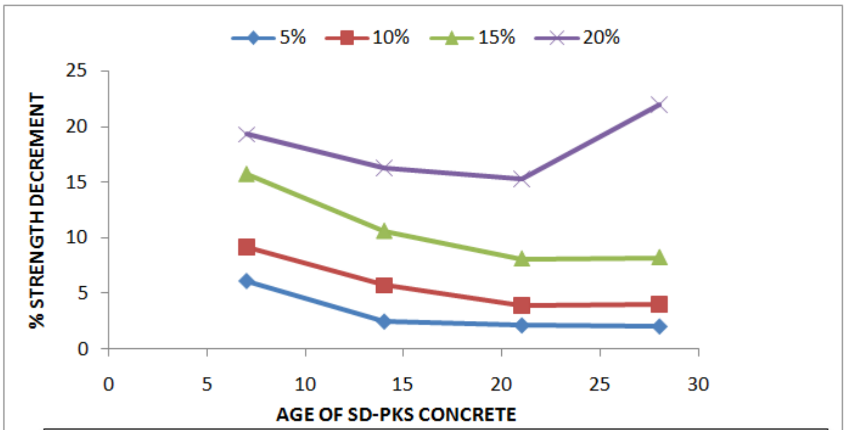

FIG.3. AGEING EFFECT OF SD-PKS CONCRETE ON COMPRESSIVE STRENGTH

3.4 Modeling the Properties of the Concrete COMPOSITES

Models developed here were of the form of Equation (2) using 0%, 10%, 20% and 30% by volume replacement.

3.4.1 Slump Model

X	0	10	20	30
F (x)	80.00	76.00	62.00	41.00

Get $(n;\ \{x\}_i^n = 0; \{f_o(x_1)_i^n = 0) =$
$n = 3;\ x_0 = 0;\ x_1 = 10;\ x_2 = 20;$
$x_3 = 30; f(x_0) = 80.00$
$f(x_1) = 76.00, f(x_2) = 62.00, f(x_3) = 41.00$
$k \coloneqq 1$
$while\ (1 \leq 3) = true$
$do:$
$j = o$
$while\ (0 \leq 3 - 1) = true$

$$f(x_1, x_1) = \frac{f(x_1) - f(x_0)}{x_1 - x_0} = \frac{76 - 80}{10 - 0} = -0.4$$

$f(0{,}10) = -0.4; \mathrm{j} = \mathrm{j} + 1 = 1$
end do;
while $(1 \leq 2) =$ true
do:

$$f(x_1, x_2) = \frac{f(x_2) - f(x_1)}{x_2 - x_1} = \frac{62 - 76}{20 - 10} = -1.4$$
$f(10,20) = -1.4; j = j + 1 = 1 + 1 = 2$
$end\ do$:
$while\ (2 \leq 2) = true$
do:
$$f(x_2, x_3) = \frac{f(x_3) - f(x_2)}{x_3 - x_2} = \frac{41 - 62}{30 - 20} = -2.1$$
$f(20,30) = -2.1; j = j + 1 = 2 + 1 = 3$
$end\ do$
$while\ (3 \leq 2) = false > do$
$end\ do$
$k = k + 1 = 1 + 1 = 2$
$while\ (3 \leq 3) = true$
do:
$j = o$
$while(0 \leq 1) = true$
do
$$f(x_0, x_1, x_2) = \frac{f(x_{1,}, x_{2,}) = f(x_0, x_{1,})}{x_2 - x_0} = \frac{-1.4 - (-0.4)}{20 - 0} = -0.05$$
$f(0, 10, 20) = -0.05; j = j + 1 = 0 + 1 = 1$
end
do
$while\ (1 \leq 1) = true$
do;
$$f(x_0, x_1, x_2, x_3) = \frac{f(x_{2,}, x_{3,}) = f(x_1, x_{2,})}{x_2 - x_0} = \frac{-2.1(-1.4)}{30 - 10} = -0.035$$
$f(10, 20, 30) = -0.035; j = j + 1 = 1 + 1 = 2)$
$end\ do$
$while\ (2 \leq 1) = false\ > do$
$end\ do$
$k = k + 1 = 2 + 1 = 3$
$while\ (3 \leq 3) = true$
do
$j = o$
$$while\ (0 \leq 0) = true$$
do;
$$f(x_0, x_1, x_2, x_3) = \frac{f(x_1, x_2, x_3) - (x_0, x_1, x_2)}{x_3 - x_0} = \frac{-0.035 - (-0.05)}{30 - 0} = 0.0005$$
$f(0, 10, 20, 30) = 0.0005; j = j + 1 = 0 + 1 = 1$
$while\ (1 \leq 0) false\ > do$
$end\ do$
$k = k + 1 = 3 + 1 = 4$
$while\ (4 \geq 3) = false > do$
$end\ do$
$stop$
Polynomial becomes:
$$S_m = P_3(x) = 80 - 0.4x - 0.05x(x - 10) + 0.0005x\ (x - 10)(x - 20)$$

3.4.2 28^{th} – Day Compressive Strength Model

x	0	10	20	30
F(*x*)	20.05	19.25	15.65	14.55

$Get\ (n; \{x\}_i^n = 0; \{f_0(x_i)_i^n = 0) =$
$n = 3;\ x_0 = 0, x_1 = 10, x_2 = 20, x_3 = 30$
$f(x_0) = 20.05, f(x_1) = 19.25, f(x_2) = 15.65, f(x_3) = 14.55$
$k \coloneqq 1$

$while\ (1 \leq 3) = true$
do:
$j \coloneqq 0$
$while\ (0 \leq 3 - 1) = true$
do;

$$f(x_{0,}x_1) = \frac{f(x_1) - f(x_0)}{x_1 - x_0} = \frac{19.25 - 20.05}{10 - 0} = -0.08$$

$f(0, 10) = -0.08; \mathrm{j} = \mathrm{j} + 1 = 0 + 1 = 1$
$while\ (1 \leq 2) = true$
do;

$$f(x_{1,}x_2) = \frac{f(x_2) - (x_1)}{x_2 - x_1} = \frac{15.65 - 19.25}{20 - 10} = -0.36$$

$f(10, 20) = 0.36; \mathrm{j} = \mathrm{j} + 1 = 1 + 1 = 2$
$while\ (2 \leq 2) = true$
do:

$$f(x_{2,}x_3) = \frac{f(x_3) - (x_2)}{x_3 - x_2} = \frac{14.55 - 15.65}{30 - 201} = -0.11$$

$f(20, 30) = -0.11; j = j + 1 = 2 + 1 = 3$
$while\ (3 \leq 2) = false > do$
$end\ do$
$k = k + 1 = 1 + 1 = 2$
$while\ (2 \leq 3) = true$
do
$j = 0$
$while\ (0 \leq 1) = true$
do

$$f(x_{0,}x_{1,}x_2) = \frac{f(x_{1,}x_2) - f(x_{0,}x_{1,})}{x_2 - x_0} = \frac{-0.36 - (-0.08)}{20 - 0} = 0.014$$

$f(0, 10, 20) = -0.014; j = j + 1 = 0 + 1 = 1$
$while\ (1 \leq 1) true$
do

$$f(x_{1,}x_{2,}x_3) = \frac{f(x_{2,}x_3) - f(x_{1,}x_{2,})}{x_3 - x_1} = \frac{-0.11 - (-0.36)}{30 - 10} = -0.0125$$

$f(10, 20, 30) = 0.0125; j = j + 1 = 1 + 1 = 2$
$while\ (2 \leq 1) = false > do$

$end\ do$

$k = k + 1 = 2 + 1 = 3$
$while\ (3 \leq 3) = true$
do
$j = 0$
$while\ (0 \leq 0) = true$
do

$$f(x_{0,}x_{1,}x_{2,}x_3) = \frac{f(x_{1,}x_{2,}x_3) - f(x_{0,}x_{1,}x_{2,})}{x_3 - x_0} = \frac{0.0125 - (-0.014)}{30 - 0} = 0.000088$$

$f(0, 10, 20, 30) = 0.00088; j = j + 1 = 0 + 1 = 1$
$while\ (1 \leq 0) = false > do$
$end\ do$
$k = k + 1 = 3 + 1 = 4$
$while\ (4 \leq 3) = false\ > do$
$end\ do$
$stop$

Polynomial becomes

$$S_{28} = P_3(x) = 20.05 - 0.08x - 0.014x(x - 10) + 0.00088x\ (x - 10)(x - 20)$$

3.5 Model Validation

The models developed for the slump/workability and 28th day compressive strength, were validated using a statistical tool called coefficient of determination, R^2, which is determined according to Equation 3.

$$R^2 = \frac{\Sigma(y_{est} - \bar{y})^2}{\Sigma(y - \bar{y})^2} \quad (3)$$

Where $y_{est} = predicted\ concrete\ property\ value\ from\ model$

$y = Experimental\ or\ actual\ property\ value$

$\bar{y} = average\ experimental\ property\ value.$

Using Equation 3, R^2 value of 0.77 and 0.85 were obtained for slump and 28^{th} day compressive strength model respectively.

IV. CONCLUSION AND RECOMMENDATION

4.1 Conclusion

From preceding discussions, the following conclusions have been drawn;

1. The workability of SD-PKS concrete reduces with increase in the by-products concentration.
2. The compressive strength of SD-PKS concrete reduces as the concentration of the by-products increases
3. SD-PKS aggregate concrete produces a compressive strength of over $17N/mm^2$ up to 15% replacement.
4. The concrete produced from these by products can be used as lightweight concrete.
5. The models deduced can be used adequately to predict properties SD-PKS shell aggregate concrete as they corroborated well with experimental values depicted by the high coefficient of determination values.

4.2 Recommendations

1. Further studies on SD-PKS aggregate concrete should be conducted using other designs.
2. Investigation on the effect of varying the SD and PKS concentration on concrete property should be done.

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