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OPTIMIZATION OF COMPRESSIVE STRENGTH OF CONCRETE WITH PIG-HAIR FIBERS AS FIBER REINFORCEMENT AND GREEN MUSSEL SHELLS AS PARTIAL CEMENT SUBSTITUTE

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ABSTRACT: The feasibility of different waste materials as substitute to the main components of concrete is attracting attention nowadays. In relation to that, this study focuses on determining the effects of combining two waste materials namely, pig-hair fibers (PHF) as fiber reinforcement and crushed green mussel shells (GMS) as partial cement substitute to the properties of concrete. Response Surface Methodology (RSM) was used to model the relationship between the response and the factors considered. Using central composite design (CCD) to establish the design of experiment, the researchers was able to reduce the required number of experimental runs to 20 from a total of 27 runs for 3 level full factorial experimental program that is common for responses with nonlinear behavior. Optimization was conducted to determine the optimum amount of PHF and GMS in concrete that could yield maximum compressive strength while keeping the workability at an acceptable level. As for the results, an increase in compressive strength of concrete was recorded with the incorporation of PHF and GMS to concrete. However, decrease in workability was experienced due to the amount of fiber reinforcement present in the mix. Results of RSM suggested an optimum combination of 0.70% PHF content and 7.81% GMS partial cement substitute at 0.47 water-cement ratio (w/c) to achieve 27.40 MPa and 2.78 MPa compressive and tensile strength respectively with a minimum recommended slump of 25 mm for concrete beams and columns as per ACI. Based on these results, PHF-GMS concrete could be used in structures not requiring compressive strength above 28 MPa. With the use of GMS as a partial cement substitute, it could reduce the overall cement requirement for a project thus incurring savings and most importantly promotes the use of environment friendly materials.

Keywords: Pig-hair Fibers, Green Mussel Shells, Response Surface Methodology, Concrete

1. INTRODUCTION

Concrete is considered as the second most-consumed substance in the world next to water. As of 2012, a total of 11.5 billion tons of concrete are produced each year and is expected to increase to approximately 18 billion tons a year by 2050 [1]. Based on a study by Rubenstein [2], approximately 5% of the total carbon dioxide emission all over the world is constituted to concrete production. Aside from pollution, another problem on the increasing demand for concrete production is the shortage on locally available raw materials especially in remote areas

Due to the problems stated above, some researchers [3], [4], [5] today are inclined to study the feasibility of using other materials as substitute to the main components of concrete i.e. cement, sand and gravel. These previous studies were conducted to help minimize the negative effects of concrete production on the environment and provide cheaper alternative for the consumers. Addition of natural fiber reinforcement to improve strength and partial cement replacement are examples of application of green concrete technology.

Generally, materials with high lime or silica content could be a potential partial substitute to cement. In relation to this, most sea shells are composed of calcium carbonate or limestone that made up almost 95% of its composition. Due to the presence of lime, shells exhibit cementitious characteristics when subjected to refinement. A chemical analysis was conducted by Etuk [3] to determine the chemical composition of powdered shells and based on the results, shells contains large amount of CaO (calcium oxide) and SiO_2 (silica) that are the two main chemical compounds in ordinary Portland cement making it feasible as partial cement substitute. Scallop shell (SS) powder was used as cement additive for grouting, results showed that the unconfined compressive strength of sand piece samples increased by 25% (120 kPa to 150 kPa) upon incorporation of 10% SS powder [4]. Also, a study was conducted on the utilization of Green Mussel Shells (GMS) and results showed that incorporating GMS into concrete as partial cement substitute improves its compressive and tensile strength by 48.28% and 68.06% respectively [5]. These studies illustrated the potential of limestone from sea shells as substitute cementitious material for concrete.

Fiber reinforcement in concrete is used to provide additional durability and improve its overall performance. Polymer based synthetic fibers are the ones that are commercially and commonly used in the construction industry as reinforcement. They can be classified as microsynthetic fibers, macrosynthetic fibers or a combination of both. Though it is effective in strengthening concrete, synthetic fibers are more expensive compare to other alternative fiber reinforcement. Studies on natural fibers such as coconut fiber, jute fiber, human hair and etc. as fiber reinforcement to concrete have been conducted by different researchers. Pig Hair Fibers (PHF) are also used as fiber reinforcement to concrete. Study shows that using PHF as fiber reinforcement not only improves the tensile strength of concrete but also its compressive strength [6].

Upon discussing the potential feasibility of the two materials (GMS and PHF) as an alternative component for concrete, it is quite interesting to study these materials when applied simultaneously to concrete. This study could determine whether their combination will yield better results or their interaction can have a negative effect on each other's characteristics. With the use of various statistical analysis techniques, effect of interaction of these two materials on a particular response can be analyzed. Statistical analysis like ANOVA can determine the level of significance of each factor and their interaction to the response. Along with Response Surface Methodology (RSM), it can provide non-linear analysis of results that captures curvature on the response plot. RSM also enables the researcher to determine optimum level of factors to come up with the maximum possible yield and also generate a prediction model for the fresh and hardened properties of concrete based on the proportion of parameters involved.

2. METHODOLOGY

Experimental approach in combination with statistical tools is the fundamental methodology used in this study. Shown in Fig. 1 is the systematic plan used in conducting this research.

2.1 Preparation and Processing of PHF & GMS

As discussed in the introduction, two waste materials were used for this study. PHF and GMS were processed and tested for their physical properties. PHF were collected from a slaughterhouse in Cavite and then the fibers were washed and dried under the sun for 48 hours to remove impurities accumulated during the dehairing process. The GMS used in this study are called the "Asian Green Mussels". They are the ones commonly found in the Philippine shores specifically in the Manila Bay. To extract its lime content, the shells were heated in a pan while continuously stirring for three hours until it became brittle. After heating, the shells were crushed into powdered form. To ensure uniformity in the particle size, crushed shells were sieve with 1 mm diameter opening. These powdered GMS were used as partial cement substitute. PHF content and GMS partial cement replacement are the main parameters of this study.

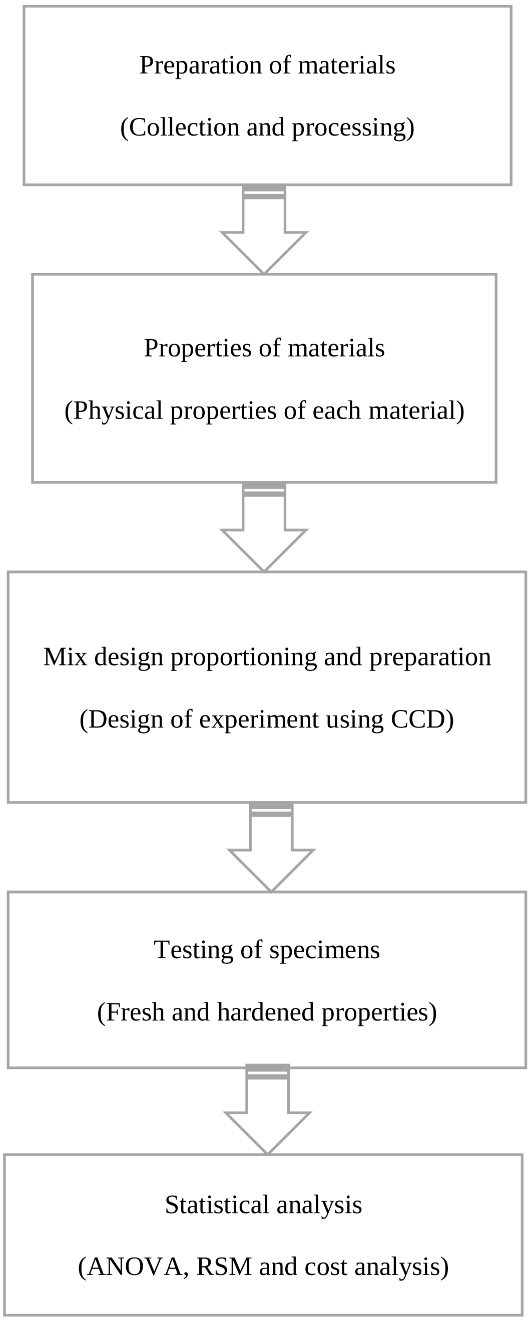

Fig.1 Flowchart of systematic plan of the study

2.2 Design of Experiment

The authors established proportions based on the best mix design suggested by the previous studies of Talagtag et al. [5] and Lejano et al. [6]. For PHF, 3 levels (0.6%, 0.8% & 1.0%) per volume of concrete of fibers were used. Also, 3 levels (5%, 10% & 15%) of partial cement replacement were used for GMS. These combinations were investigated for different water-cement ratio of (0.4, 0.5 & 0.6). Combination of these parameters is set using central composite design (CCD) as shown in Fig. 2. A total of 10 samples were made for each mix design for compressive and tensile strength test.

2.3 Making of Specimen and Testing

Mixing of concrete specimen was based on ASTM C192 [7] or the Standard Method of Making and Curing Test Specimen in the Laboratory. Dry mixing technique was used for the mixing of concrete. This mixing technique prevents accumulation of air pockets in the mixture thus making it more ideal when working with fiber reinforced concrete.

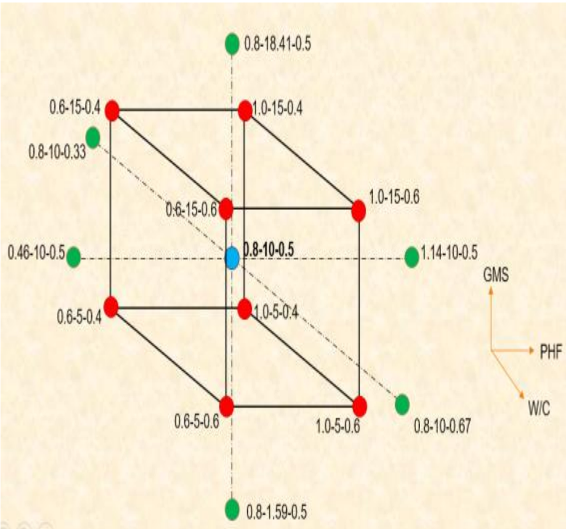

Fig.2 Central composite design of the study

3. RESULTS AND DISCUSSION

The results of the 20 mix design tested for workability, compressive and split-tensile strength are shown in Table 1. These mix design combinations were established using central composite design (CCD) to reduce the required number of experimental runs to 20 from a total of 27 runs for 3 level full factorial experimental program that is common for responses with nonlinear behavior.

Table 1 Experiment results

Mix Design	Slump (mm)	Compressive Strength (MPa)	Tensile Strength (MPa)
0.6-5-0.4	23	32.23	2.73
1.0-5-0.4	18	31.27	3.44
0.6-15-0.4	28	25.81	2.49
1.0-15-0.4	14	23.29	2.25
0.6-5-0.6	35	15.13	1.58
1.0-5-0.6	28	16.19	2.09
0.6-15-0.6	32	14.31	1.62
1.0-15-0.6	27	11.21	1.83
0.46-10-0.5	26	25.41	2.53
1.14-10-0.5	19	20.00	2.51
0.8-1.59-0.5	22	20.14	2.22
0.8-18.41-0.5	23	15.92	2.03
0.8-10-0.33	10	31.21	2.84
0.8-10-0.67	38	13.36	1.24
0.8-10-0.5	26	26.34	2.69
0.8-10-0.5	26	26.03	2.87
0.8-10-0.5	24	25.71	2.78
0.8-10-0.5	29	24.00	2.75
0.8-10-0.5	29	23.96	2.72
0.8-10-0.5	27	23.22	2.58

Note: Mix Design are coded as PHF percentage – GMS cement replacement – water cement ratio.

3.1 Workability of Fresh Concrete

Shown in Table 1 are the results of the slump test for each mix. Overall, the workability attained during the experiment ranged from 10 to 38 mm. Based on this result, PHF-GMS concrete would be suitable for foundation application with light reinforcement. Furthermore, with high levels of water cement ratio, reduction of slump due to the increase of fiber content tends to become less compared to samples with lower w/c ratio. With higher water cement ratio, this concrete mixture could be used also for beams and columns. Fig. 3 shows the relation between the w/c ratio and the recorded slump of PHF-GMS concrete mix.

Comparing the slump of PHF-GMS concrete to the control specimen, addition of PHF and GMS resulted to a decrease in workability of concrete. (The control specimens are those without GMS cement replacement and without PHF reinforcement.) These results were expected due to the fact that previous studies conducted on the application of each material also resulted to a decrease in workability.

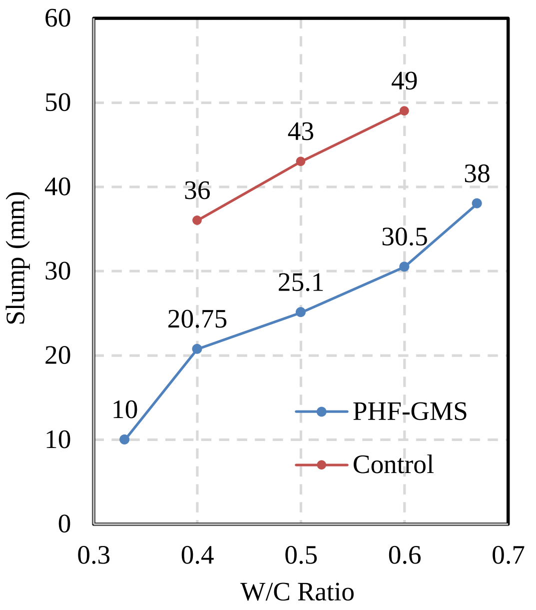

Fig.3 Average slump for different w/c ratio (average slump vs. W/C ratio)

3.2 Compressive Strength of Concrete

Compressive strength of each mix design was computed using the average of 5 concrete cylinders tested. Like normal concrete, PHF-GMS concrete also experienced an inverse proportional relationship between the w/c ratio and compressive strength as shown in Figure 4. Comparing the results of the PHF-GMS combination to the control specimens, it can be seen that the compressive strength of concrete increased by 21.47% at 0.4 w/c, 32.71% at 0.5 w/c and 5.41% at 0.6 w/c. PHF-GMS concrete with W/C ratio of 0.5 yielded the highest compressive strength gain, this is due of the fact that the optimum content for the two materials (0.8% and 10% respectively) were at the center of the design that is where the 0.5 w/c ratio is also located. However, among the three factors considered in this study, the w/c ratio still had the most effect to the resulting compressive strength as well as the workability of concrete.

Aside from the w/c ratio, another factor that showed significant effect to the compressive strength is the GMS content. The graph shown in Figure 5 describes the behavior of the compressive strength with respect to the different amount of GMS as partial cement substitute used in the mixture. Results in Fig. 5 were analyzed using a fixed PHF content of 0.8% per volume of concrete and 0.5 W/C ratio.

It can be seen that higher levels of GMS cement replacement had a negative effect on the strength of concrete. This decrease in strength may be accounted to the unutilized lime-silica reaction of excess lime from higher GMS content to the silica present in Portland-pozzolanic cement used.

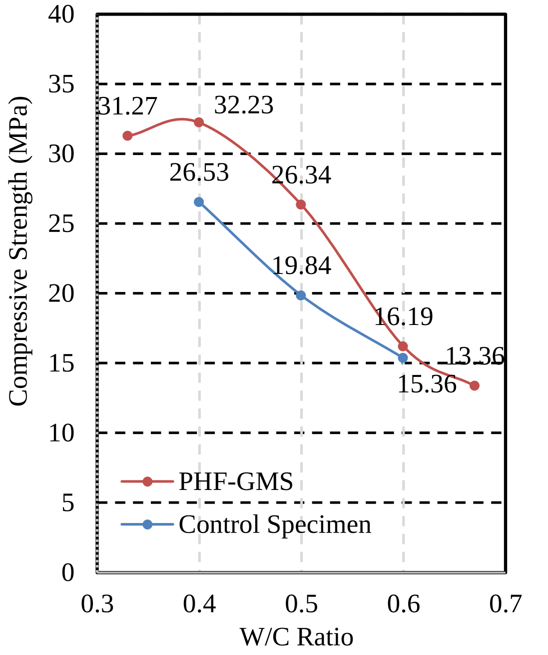

Fig.4 Maximum compressive strength at different w/c ratio (maximum compressive strength per w/c ratio)

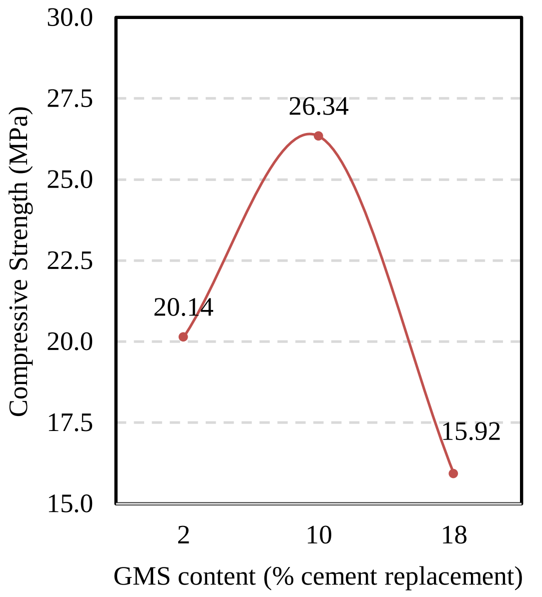

Fig.5 Compressive strength for varying GMS content (compressive strength of concrete vs GMS content)

As for the results of the analysis of variance for compressive strength, the 3 factors (PHF content, GMS partial cement substitute and W/C ratio) were all significant to the compressive strength of concrete. Among these factors, w/c ratio has the highest level of significance. This is due to the fact that W/C ratio had the most effect in terms of increasing/decreasing the workability of concrete as it changes. Between the two materials incorporated, PHF content and GMS partial cement substitute, the latter had more significant effect on the compressive strength of concrete. The fact that the cement content of ordinary concrete greatly affects its resulting properties, replacing some parts of it with pure lime from GMS would also have a significant effect on strength of concrete.

After determining significant factors and interaction, results were plotted to generate a response surface that represents the behavior of the compressive strength with respect to the PHF reinforcement content and GMS partial cement substitute. Combination of PHF and GMS are plotted for different water cement ratio as shown in Figures 6 to 8.

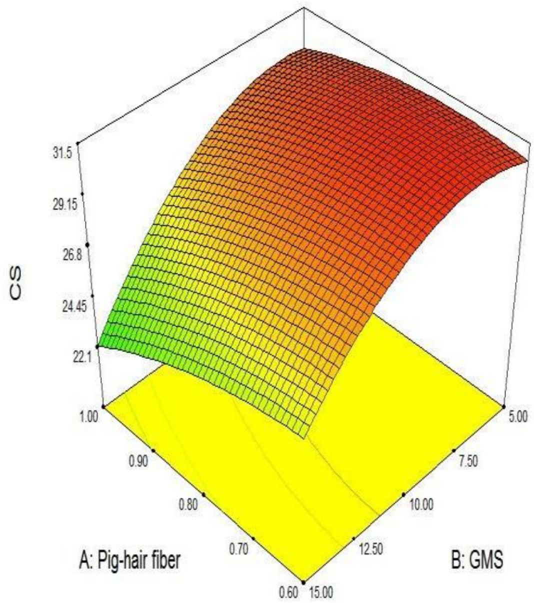

Fig.6 Compressive strength 3D surface for w/c=0.4

Based on the 3d response surface plots for compressive strength on different water cement ratio, it was clearly observed that there is a nonlinear behavior of compressive strength with the variation GMS content from 5% to 15% for the 3 W/C ratio level. At W/C ratio of 0.4, the maximum value of compressive strength was located near the minimum amount of GMS content considered which is at 5%. However, as the W/C ratio increases from 0.5 and 0.6 level, a shift on the optimum GMS content near the center of surface was observed. This means that, high w/c ratio promotes better utilization of lime content from GMS that is beneficial in the strength gain of concrete with GMS as partial cement substitute. Substituting type 1P (portland-pozzolan) cement with GMS led to adequate lime-silica reaction between the reactive silica of fly ash and lime extracted from the green mussel shells.

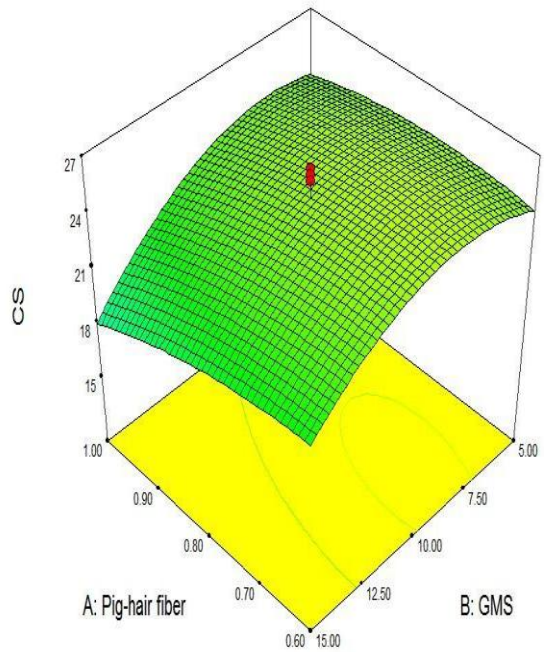

Fig.7 Compressive strength 3D surface for w/c=0.5

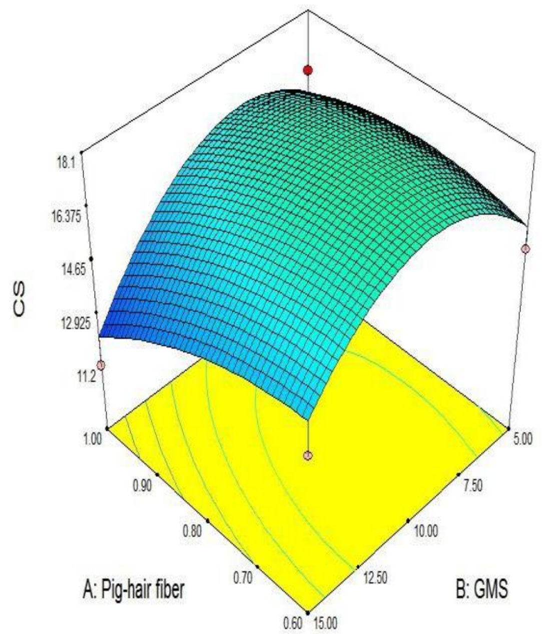

Fig.8 Compressive strength 3D surface for w/c=0.6

3.3 Split Tensile Strength of Concrete

Generally, the tensile strength recorded follows the same behavior as the compressive strength. It can be seen also from the results that an increase in tensile strength of concrete was experienced when increasing the fiber content to 1% compared to specimen containing only a minimum amount of 0.6%. However, maintaining the PHF content of concrete to its optimum percentage as suggested by the previous study had the most positive effect in terms of effectively increasing the tensile strength while keeping the slump of concrete at an acceptable level. This behavior of the tensile strength of concrete to varying PHF content in concrete was illustrated in Fig. 9.

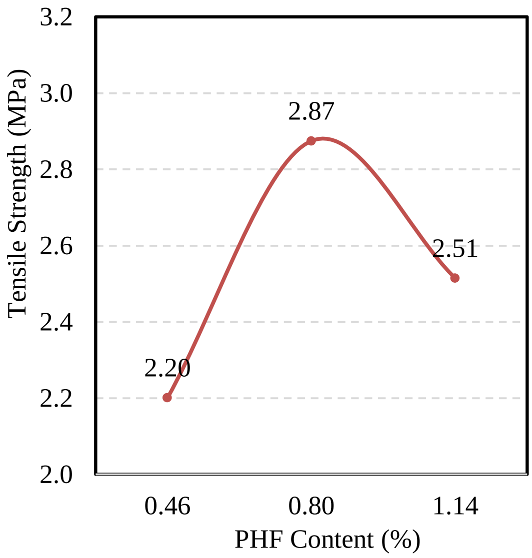

Fig. 9 Tensile strength for varying PHF content (tensile strength of concrete vs PHF content)

A 2.87 MPa tensile strength was recorded using the optimum condition suggested by previous studies that is about 74% higher compared to the control specimen. It is evident that increasing the fiber content of concrete really increases its tensile strength, however, further increase in PHF content may result to reduced workability and accumulation of air voids that could cause strength reduction in concrete.

3.4 Optimization

The regression models in Eqs. (1), (2) and (3) were used in predicting the optimum mix design for the PHF and GMS combination.

$$CS = 32.179 + 24.565A + 0.964B - 8.493C - 0.715AB + 9.000AC + 2.150BC - 17.042A2 - 0.093B2 - 83.018C2 \quad (1)$$

$$TS = -2.299 + 5.808A + 0.101B + 13.118C - 0.156AB + 1.563AC + 0.303BC - 2.750A2 - 0.0078B2 - 22.138C \quad (2)$$

$$S = 6.402 - 15.660A - 0.019B + 63.038C \quad (3)$$

where:
CS = Compressive strength of concrete, MPa
TS = Split-Tensile strength of concrete, MPa
S = Slump of concrete, mm
A = Pig-hair fiber content, %
B = Green mussel shell partial cement subs., %
C = Water/cement ratio

The main objective of the optimization was to generate the maximum possible compressive strength while keeping the workability of the mixture at an acceptable level, which for this case, a minimum slump of 25 mm. The optimum mix design was determined using the numerical optimization tool of Design Experts® as shown in Table 2. These results showed that combining PHF and GMS into concrete could yield a maximum compressive strength of 27.394 MPa with an acceptable slump of 25 mm using the optimum combination generated.

Table 1 Optimum mix design

Factors/Response	Optimum Value	Unit
PHF Content	0.70	%
GMS Content	7.81	%
W/C ratio	0.47	
CS	27.40	MPa
Slump	25	mm

3.5 Cost Analysis

The cost analysis was focused on determining the economy of the application of the two materials under study. Direct cost such as materials, labor and miscellaneous expenses were considered for PHF and GMS. The fact that both of these materials were considered as wastes, its materials cost could be assumed as zero. However, gathering and processing these materials into concrete component induced labor and operations cost. Table 3 shows the total cost derived for each component material used in the concrete. Also, shown in Table 4 is the cost comparison of ordinary concrete (OC) and PHF-GMS concrete (PGC). Concrete strengths of control specimen at different w/c ratio considered (15.36 MPa, 19.84 MPa and 26.53 MPa) were used as the base strength for OC and PGC.

Table 2 Unit price of materials

Material	Unit Cost	
PHF	4.50	Php / kg
GMS	8.06	Php / kg
Cement	6.00	Php / kg
Gravel	0.71	Php / kg
Sand	0.35	Php/kg

Comparing the results showed that incorporating PHF and GMS reduces the cement content requirement in concrete by the increase in w/c ratio to achieve a particular compressive strength. Savings of about 0.78%, 7.22% and 10.11% were recorded compared to ordinary concrete with 0.6, 0.5 and 0.4 w/c ratio respectively.

Table 3 Cost comparison per strength requirement

CS (MPa)		W/C	GMS	PHF	Cost per cu.m (Php)
15.36	OC	0.60	0	0	2,815.43
MPa	PGC	0.63	9.86	0.68	2,793.43
19.84	OC	0.50	0	0	3,166.70
MPa	PGC	0.58	9.22	0.68	2,938.08
26.53	OC	0.40	0	0	3,693.61
MPa	PGC	0.48	8.3	0.70	3,320.16

4. CONCLUSION

This study showed that the parameters considered pig-hair fiber reinforcement, GMS partial cement substitute and water cement ratio had a significant individual effect to the resulting properties of concrete. Based on the results, combining pig-hair fibers and GMS into concrete further increased the compressive strength of concrete when compared to the results obtained on the research about application of GMS only by about 13.19% (from 23.27 MPa to 26.34 MPa) at 0.5 w/c ratio. However, reduction in workability was experienced upon the combination of these two materials into concrete. Generally, increasing the amount of PHF on the mixture tends to decrease the workability of the fresh concrete. Adjustment of the overall water content on the mix could be done to address the decrease in workability caused by fiber reinforcement. Compressive strength as high as 32.23 MPa was recorded for PHF-GMS concrete at 0.4 w/c ratio which yielded a slump of only 14 mm thus making it unacceptable for industry application. The maximum compressive strength with above minimum acceptable slump of 26mm was obtained from the 0.8%-10%-0.5 (PHF-GMS-W/C) combination that yielded 26.34 MPa which was 32.74% higher than ordinary concrete strength with the same w/c ratio.

Using the mix design obtained from optimization on actual specimens, PHF-GMS concrete obtained a compressive strength of 26.58 MPa and slump of 26mm. Results suggest that PHF-GMS could be used in structures not requiring above 28 MPa compressive strength or high strength concrete. These include residential houses, low rise buildings and also concrete pavements. And with the use of GMS as a partial cement substitute, it could reduce the overall cement requirement for a project thus incurring savings and most importantly promotes the use of environment friendly materials.

5. ACKNOWLEDGMENT

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