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Evaluation of the Effects of Combining Pig-Hair Fiber as Fiber Reinforcement and Green Mussel Shells as Partial Cement Substitute to the Properties of Concrete

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Abstract: The feasibility of different waste materials as substitutes to the main components of concrete is attracting attention nowadays. This study mainly focuses on determining the effects of combining two waste materials i.e. pig-hair fiber and crushed green mussel shells to the properties of concrete. The pig-hair fibers (PHF) are used as fiber reinforcement to concrete and the crushed green mussel shells (GMS) are used as a partial cement substitute. With the use of statistical analysis software, Response Surface Methodology (RSM), the design of an experimental program was generated. The result of the experimental program is used to investigate the interaction between these two materials and their effect on the compressive strength of the concrete. RSM was used to determine the optimum amount of PHF and GMS that can be incorporated to the concrete to achieve the highest compressive strength while keeping the workability of the concrete at an acceptable level.

In this study, the Central Composite Design (CCD) is used to fit the model for the materials under study. A total of 12 experimental runs were used in this study, with 3 levels assigned to each factor. 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 substitute were used for GMS. These combinations were incorporated in different water-cement ratio of 0.4, 0.5 and 0.6. The effects of these factors and their interaction were investigated and analyzed. Results show that addition of these materials has a significant effect on the resulting properties of concrete. An increase in the compressive strength of concrete is recorded with the incorporation of these materials. However, decrease in workability too are experienced due to the amount of fiber reinforcement present in the mix. Results of RSM suggests an optimum combination of 0.70% PHF content, 9.09% GMS partial cement substitute and at 0.50 w/c ratio to achieve 26.73 MPa with an acceptable slump of 25 mm.

Key Words: Concrete; Pig-hair fiber; Green mussel shell; Compressive Strength, Workability

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 (Mehta & Montiero, 2013). Most of the buildings and structures built today are made out of concrete. Along with the increase in demand for concrete come its negative effects on the environment. Based on a study by Rubenstein (2012), 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, many researchers today are inclined to study the feasibility of using other materials as substitute to the main components of concrete i.e. cement, sand, gravel and water. These studies are developed 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, GMS composed of calcium carbonate or limestone that made up almost 95% of its composition. Due to the presence of lime, GMS exhibits cementitious characteristics when subjected refinement. Earlier study by Ngo et al. (2014) on the utilization of GMS indicated that incorporating GMS into concrete as partial cement substitute improves its compressive and tensile strength by 48.28% and 68.06% respectively thus proving its potential 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 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. 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. (Templonuevo et al., 2013).

Upon discussing the potential feasibility of the two materials (GMS and PHF) as an alternative components 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 we can analyze the effect of interaction of these two material on a particular response. Statistical analysis like Analysis of Variance or ANOVA can determine the level of significance of each factor and their interaction to the response. Along with RSM, it can provide non-linear analysis of results that captures curvature on the response plot. This will enable 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

The systematic plan in Fig. 1 shows the methodology used in conducting the study.

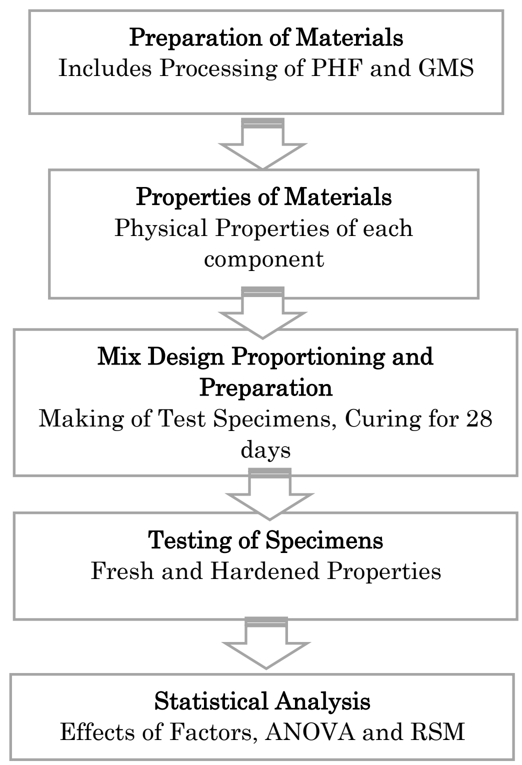

Fig. 1. Systematic Plan of the Study

2.1 Parameters and Response Variable for the Study

As discussed in Section 1, two waste materials are used for this study. PHF and GMS were processed and tested for their physical properties. PHF were collected from the Monterey plant in

Cavite, the fibers were washed and dried under the sun for 48 hours to remove impurities accumulated during the dehairing process. These fibers have lengths from 20 mm to about 40 mm. The GMS used in this study are called the "Asian Green Mussels", there are the ones commonly found in 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. Remaining particles retained were crushed again to achieve less than 1 mm particle size. These powdered GMS were used as partial cement substitute. PHF content and GMS partial cement replacement are the main parameters for this study.

Effects of these parameters to the response (i.e. compressive strength and workability) were investigated. Compressive strength is used as indicator of the quality and overall performance of concrete. The compressive strength of concrete is said to be influenced by several factors on its design mix. Factors such as, quality of materials, water-cement ratio, cement content and age of concrete affects the resulting fresh and hardened properties of concrete. Proportion of each component materials in concrete is important to come up with the desired concrete strength. Another property of concrete considered in this study is the workability, it is the measure of how easy it is for the mix to be handled, molded, and compacted. Slump is used to determine the workability of concrete. Depending on the application, slump requirement ranges from 25 mm minimum to about 150 mm maximum.

2.2 Mix Design Proportioning

The authors established proportions based on the best mix design suggested by previous studies (Templonuevo et al., 2013; Ngo et al., 2014). For PHF, 3 levels (0.6%, 0.8% & 1.0%) per volume of concrete of fibers is used. Also, 3 levels (5%, 10% & 15%) of partial cement replacement is used for GMS. These combinations will be investigated for different water-cement ratio of (0.4, 0.5 & 0.6). Combination of these parameters are set using central composite design (CCD). Generally, CCD consist of 2^k factorial runs, 2k axial runs and 4-7 center runs. For this study where the number of factors is k = 3 with 5 center runs assigned, a total of 20 experimental runs were needed. Each design mix combination had 5 replicates to provide better precision in determining the compressive of the specimens.

2.2 Specimen Preparation and Testing

Mixing of concrete specimen was based on ASTM C192 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.

After mixing the concrete, concrete specimen samples were molded. As per ASTM C192, concrete cylinders of 6" diameter and 12" in height were made from the mix as specimens for compressive strength test. Each specimen was cured for 28 days before being tested using the Universal Testing Machine (UTM) for its compressive strength.

3. RESULTS AND DISCUSSION

The results of the 12 mix design tested for compressive strength are shown in (Table 1). Mix Design are coded as PHF percentage – GMS cement replacement – water cement ratio.

Table 1. Experiment Results

Mix Design	Slump (mm)	Compressive Strength (MPa)
0.8-10-0.33	10	31.21
0.6-5-0.4	23	32.23
0.6-15-0.4	28	25.81
1.0-15-0.4	14	23.29
0.46-10-0.5	26	25.41
0.8-1.59-0.5	22	20.14
0.8-10-0.5	26	26.34
0.8-10-0.5	26	26.03
0.8-18.41-0.5	23	15.92
0.6-5-0.6	35	15.13
0.6-15-0.6	32	14.31
0.8-10-0.67	38	13.36

3.1 Effect of W/C Ratio

Shown in Fig. 2 is a plot showing the behavior of the compressive strength of concrete with PHF and GMS. Like normal concrete, PHF-GMS concrete also experienced an inverse proportional relationship between the w/c ratio and compressive strength. It is important to capture the effect of w/c ratio to effectively investigate the contribution of incorporating the two waste materials under study. Extreme points with 0.33 and 0.67 w/c ratio are included to provide estimation of curvature on the experimental design. As for the slump, not only the w/c ratio has a significant effect on the resulting slump of the mixture but as well as the amount of PHF and GMS in the mixture.

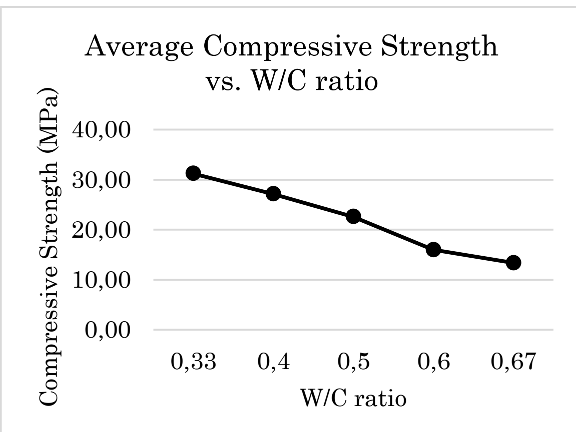

Fig. 2 Compressive Strength for different W/C ratio

3.2 Effect of Varying GMS Partial Cement Replacement

For the analysis of the effect of GMS alone in the compressive strength of concrete, other factors such as w/c ratio and PHF content into the mixture should be held constant. Fig. 3 shows the effect of GMS when PHF is fixed at 0.8% per volume content of concrete and 0.5 W/C ratio. This result supports the previous study by Ngo et al. (2014) conducted on GMS as partial cement substitute that also showed 10% to be the optimum content that can give the highest compressive strength for the concrete. 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 pozzolan cement used.

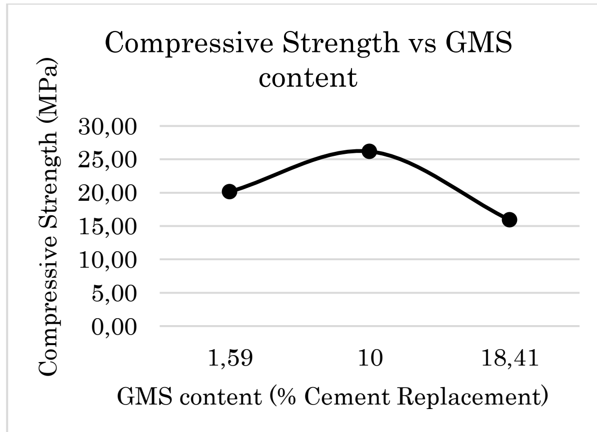

Fig. 3 Compressive Strength for Varying GMS content

3.3 Effect of Pig-Hair Fiber Reinforcement on Concrete

From the results shown in Table 1 specifically for mix design 0.6-15-0.4 and 1.0-15-0.4 with both GMS content and W/C ratio remains the same, increasing the PHF fiber reinforcement content to 1.0% results to a decrease in the slump of the concrete. As expected, increasing the fiber content reduces the slump of the mixture due to the water absorption of fibers. Moreover, the decrease in the compressive strength with the increase in amount of PFH may be indirectly accounted to the lack of proper compaction due to insufficient workability of the mix during molding of specimens.

3.4 Analysis of Variance

The analysis of variance in Table 2 is used to test the significance of the factors considered in this study i.e. A-PHF content, B-GMS cement replacement and C-water cement ratio to the resulting compressive strength of concrete. The p-value determines whether the source or factor is significant or not, significance of each factor and interaction is tested with $\alpha = 0.05$.

Results show that the model is significant with 0.012 p-value and the lack of fit of this model is insignificant. This indicates that the model fitting is adequate, it means that the regression model could accurately predict the behavior of the response based on the level of factors at a given experimental space. Results of ANOVA shows that the interaction between the parameters are significant to the compressive strength. It means that the combination of the two waste materials under study for different water cement ratio had an effect on the resulting compressive strength of concrete.

Table 2. Analysis of Variance

Source	Sum of Squares	dof	Mean Square	F Value	p-value
odel	474.68	9	52.74	803.05	0.0012
A-PHF	0.01	1	0.01	0.10	0.7767
B-GMS	8.93	1	8.93	135.94	0.0073
C-W/C	170.43	1	170.43	2594.88	0.0004
AB	0.94	1	0.94	14.24	0.0636
AC	8.01	1	8.01	121.92	0.0081
BC	7.73	1	7.73	117.72	0.0084
A^2	0.22	1	0.22	3.42	0.2056
B^2	74.39	1	74.39	1132.70	0.0009
C^2	17.56	1	17.56	267.39	0.0037
Residual	0.13	2	0.07		
Lack of Fit	0.11	1	0.11	5.57	0.2552
Pure Error	0.02	1	0.02		

3.5 3D Response Surface Model

After determining significant factors and interaction, results are 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 4 to 6.

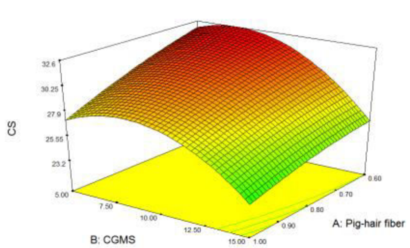

Fig. 4 Compressive Strength 3D Surface for 0.4 w/c

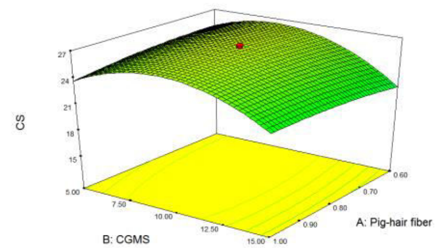

Fig. 5 Compressive Strength 3D Surface for 0.5 w/c

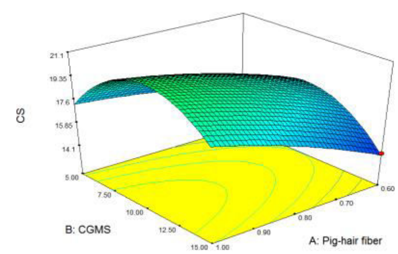

Fig. 6 Compressive Strength 3D Surface for 0.6 w/c

With water cement ratio at 0.40 as shown in Fig. 4, increasing the fiber content of the concrete reduces its compressive strength. However, as the w/c ratio increases the behavior of the response changes from decreasing to increasing. This could be accounted to the excessive loss of workability with lower water cement ratio that promotes uneven distribution of fiber reinforcement all throughout the concrete specimen. Overall, GMS value near the center of the response surface yields the highest compressive strength on three different water cement ratio. This behavior supports the plot on the effect of GMS to the compressive strength of concrete shown in Fig. 2.

3.6 Optimum Mix Design

The regression models in equation (1) and (2) were used in predicting the optimum mix design for the PHF and GMS combination. The main objective of the optimization is 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.

$$CS = 57.678 - 37.9A + 0.231B - 10.275C + 0.611AB + 89.38AC + 2.754BC - 8.289A^2 - 0.117B^2 - 142.164C^2 \quad \text{(Eq. 1)}$$

$$S = 7.084 - 21.283A + 0.098B + 64.268C \text{ (Eq. 2)}$$

where:
CS = Compressive 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

Upon generating 3D surface plots and doing regression analysis, the optimum mix design was determined with numerical optimization tool of Design Experts® as shown in Table 3. These results show that combining PHF and GMS into concrete could yield a maximum compressive strength of 26.728 MPa with an acceptable slump using the optimum value generated. As per comparison, the result of previous study using GMS alone into concrete yielded a maximum of 23.27 MPa with the same water cement ratio of 0.50. It can be seen from this comparison that addition of PHF resulted to an increase in the compressive strength of concrete with GMS.

Table 3. Optimum Mix Design

Factors/Response	Optimum Value	Unit
PHF Content	0.70	%
GMS Content	9.09	%
W/C ratio	0.5	
CS	26.728	MPa
Slump	25	mm

4. CONCLUSIONS

This study shows that the parameters GMS and water cement ratio have the significant individual effect on the properties of concrete. Though PHF alone doesn't have significant effect on the response, its interaction with other parameters exhibited significance. Regardless of whether the concrete has some additional materials incorporated into it, the relationship between its water cement ratio and compressive strength remains to be inversely proportional. Also, among the three factors investigated, w/c ratio had the most effect in terms of the increase or decrease in the properties of fresh and hardened concrete.

Generally, increasing the amount of PHF on the mixture tends to decrease the workability of the fresh concrete. Therefore, it is important to limit the PHF content level to its optimum value to prevent significant loss of workability in the mix that could lead also to low concrete compressive strength. However, it can be seen from the results that increase of fiber content on specimens without significant loss in slump (i.e. those with fiber content less than 1%) led to an increase in compressive strength.

Using the mix design obtained from optimization, PHF and GMS concrete could be used in structures not requiring compressive strength above 28 MPa. This includes residential houses, low rise buildings and also concrete pavements. 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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