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Response Surface Modelling of Concrete mixed with Fly Ash and Recycled HDPE

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Abstract: Concrete is among the widely used structural materials due to its versatile properties, however, it has negative environmental impact due to the production of some of its components, such as cement. Cement production is energy-intensive and emission-intensive because of the amount of heat needed during manufacturing. Many studies have been conducted locally in the use waste materials as a substitute to some of construction materials. In this study, it is aimed to create a model through the use of Response Surface Method that optimizes the strength of concrete mixed with Fly Ash and HDPE. There were 2 independent variables: the percentage of HDPE substitution and the percentage of fly ash substitution. The percentage of HDPE substitution were 0%, 5%, 10% and 15% by volume of fine aggregates. The percentage of fly ash substitution were 0%, 30%, and 60% by weight of the total binder. It was observed that the concrete with higher fly ash content had higher percentage increase in the strength after 28 days. HDPE as fine aggregate replacement slightly increased or did not have a significant effect on the strength. A Response Surface Model was created to predict the compressive strength, given the mix proportion of HDPE and fly ash, an equality line was used to validate.

Key Words: HDPE, fly ash, concrete, Philippines, response surface method

1. INTRODUCTION

The Philippines is considered one of the developing countries and, currently, one of its priorities is to develop its infrastructure, thus, it is noticeable that more projects are being constructed. More construction project, entails more concrete is being used. Concrete is among the widely used structural materials due to its versatile properties, however, it has negative environmental impact due to the production of some of its components, such as cement. Cement production is energy-intensive and emission-intensive because of the amount of heat needed during manufacturing. Moreover, according to Rubenstein (2012), production of a ton of cement requires 4.7 million BTU of energy or 400 pounds of coal, which has an effect to the environment.

Many studies have been conducted locally in the use waste materials as a substitute to some of construction materials (Galupino, 2015; Dungca, 2017; Dungca 2018; Dungca, 2018; Elevado, 2018;

Elevado, 2018), such as fly ash. An option towards more sustainable concrete production is replacing energy-intensive cement with supplementary cementitious materials (SCM) that are industrial by-products. Apart from economic and environmental benefits, SCMs enhance the strength and durability of concrete (Sumer, 2012; Johari, Brooks, Kabir, & Rivard, 2011; Gonen & Yazicioglu, 2007). Also, the inclusion of fly ash in the concrete mix can improve the performance of concrete at elevated temperatures or its fire performance (Nadeem, Memon, & Lo, 2014).

Aside from fly ash, an another way to make concrete more sustainable is by substituting natural aggregates with less energy-intensive and sustainable materials, such as plastic. Currently, a growing number of research has examined the feasibility of using waste plastic in concrete. Different plastic types have been investigated for their feasibility as aggregate, fibre, or filler for concrete, including polyethylene terephthalate (PET), polyvinyl chloride (PVC), high density polyethylene (HDPE), low density polyethylene (LDPE), expanded polystyrene (EPS), glass reinforced plastic (GRP), polycarbonate (PC), and polypropylene (PP) (Saikia & de Brito, 2012). In this study, the focus is on using HDPE as fine aggregates. This is due to the limited number of studies on that type as compared to PET and EPS, as well as the vast usage of HDPE in the Philippines.

In light of these two approaches towards a sustainable concrete material, the researchers recognized that there is a gap in the current studies. Most published literature on the use of HDPE as fine aggregates have dealt on testing the mechanical properties only. Little has been done to assess other properties.

A proposed Response Surface Methodology (RSM) model based on the data garnered was formulated. Response Surface Methodology (RSM) modelling is a statistical process for estimating the relationships among variables. It includes many techniques for modeling and analyzing several variables, when the focus is on the relationship between a dependent variable and one or more independent variables (Dungca, 2016).

In this study, it is aimed to create a model through the use of Response Surface Method that optimizes the strength of concrete mixed with Fly Ash and HDPE.

2. METHODOLOGY

The study dealt with the investigation of the strength performance of concrete with fly ash and recycled HDPE plastic aggregates through an experimental method of research. This was done by assessing the effect of varying amounts of substitution of fly ash and HDPE on the compressive strength of the concrete.

There were 2 independent variables: the percentage of HDPE substitution and the percentage of fly ash substitution. The percentage of HDPE substitution were 0%, 5%, 10% and 15% by volume of fine aggregates. The level of substitution cannot be increased further due to the adverse effect of HDPE on the compressive strength of concrete.

Second, the percentage of fly ash substitution were 0%, 30%, and 60% by weight of the total binder. From past studies on concrete, fly ash was found to increase the residual strength of concrete at high levels of substitution – ranging from 20% to 60% by weight of the binder.

The main parameter that was investigated in this study were the compressive strength (fc'). Cylindrical specimen with 100 x 200-mm dimension were tested for compressive strength after curing for 7, 14, 21, 28, and 120 days. The specifications of the materials used is shown on Table 1:

Table 1. Specifications of Materials Used

Gravel	Gravel from Montalban, PH with max. size of 19 mm.
Sand	Natural sand from Pampanga, PH.
HDPE Plastic Pellets	Pellets approx. 3 mm in length and diameter, recycled from various HDPE products like post-consumer plastic.
Cement	Cement Type 1P Portland Cement
Fly Ash	Class F Fly Ash. As per ASTM C618, Class F has pozzolanic properties, less than 5% of CaO and more than 50% of SiO2+Al203+Fe2O3.
Water	Clean tap water.

With 2 independent mix design variables, fly ash and HDPE percent substitution, at 3 and 4 levels, respectively, giving a total of 12 types of mixes.

The preparation of the samples were divided into 3 batches based on the amount of fly ash substitution (0%, 30%, 60%). The concrete specimens were mixed and casted in accordance with ASTM C192 and ASTM C39 in the form of 100 x 200-mm cylindrical specimens. After 24 hours of being casted, the specimens were removed from the molds and placed in a water bath at room temperature.

The cylindrical specimens were used to assess the compressive strength of the alternative concrete. Before placing in the cylindrical molds, the freshly mixed concrete was tested for slump in accordance with ASTM C143 and adjustments were made to achieve a workable concrete mix. The hardened concrete was tested for their compressive strength in accordance with ASTM C39, at different curing days, namely, 7, 14, 21, 28 and 120 days. The 28th day strength was the basis for assessing the effect of the substitutions on the compressive strength of concrete.

Further analysis were made through the graphs of the strength development and the individual effect of each substitution on the response variables. With the objective of finding the optimum amount of percent substitutions, the response surface method (RSM) analysis was carried out. A response surface model equation was developed for each response variable.

3. RESULTS AND DISCUSSION

3.1 Compressive Strength Tests

Large portion of the concrete strength developed in the first 14 days of curing, ranging from 12.95% to 54.65% increase from 7th day strength, the data is shown on Table 2. It was observed that the concrete with higher fly ash content had higher percentage increase in the strength after 28 days. The addition of fly ash improved the long-term strength. The rate of strength increase of Portland cement concrete slows down, the opposite happens to fly ash concrete due to the continued pozzolanic reaction with water in the latter ages.

Table 2. Compressive strength of the specimen

MIX	Compressive Strength, MPa				
	7	14	21	28	120
0F-0H	29.65	33.49	34.02	34.20	34.38
0F-5H	15.69	18.41	20.91	28.57	28.63
0F-10H	23.69	34.87	38.52	38.60	38.89
0F-15H	23.76	27.48	31.14	30.89	31.32
30F-0H	20.42	27.91	31.76	33.73	34.34
30F-5H	15.76	21.43	26.79	27.09	28.19
30F-10H	13.54	19.16	21.00	24.92	26.47
30F-15H	14.41	20.68	22.29	22.91	25.40
60F-0H	8.22	12.71	17.17	17.39	19.94
60F-5H	10.48	14.75	17.82	20.50	22.45
60F-10H	8.06	11.77	16.03	17.54	19.79
60F-15H	9.40	14.08	16.96	20.47	21.95

3.2 Response Surface Methodology

One of the main objectives of this study was to build a model that would be useful in predicting the compressive strength, given the mix proportion of HDPE and fly ash as well as finding the optimum mix proportions for a given response criterion, shown on Figure 1.

Different models were investigated, but based on the adjusted r-squared, the quadratic model was found to be the most suitable. The backward elimination analysis was used to increase the precision of the model.

Before proceeding to optimization, the fitted models were examined to ensure that they give sufficient approximation of the results obtained in the experimental conditions.

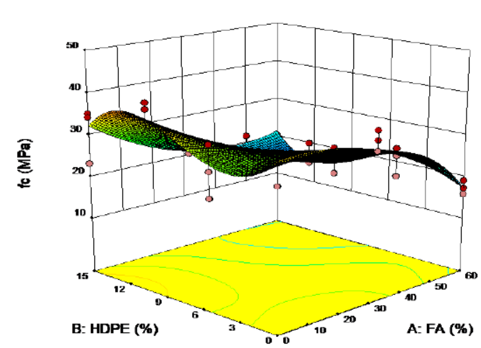

Figure 1. Response Surface Model of the Study

For the fc', an equality line was used to validate, it was found out that the model has a high accuracy in predicting the fc'.

4. CONCLUSIONS

Majority of the concrete strength development occurred in the first 14 days of curing, with percentage increases relative to 7 days ranging from 12.95% to 54.65%. After 28 days, concrete with higher fly ash content showed a higher rate of increase due to delayed pozzolanic reaction of fly ash with water.

The control concrete exceeded the target compressive strength of 25 MPa with an average strength of 34.20 MPa. Among the alternative concrete mixes, 0F-10H attained the highest strength with 38.60 MPa while 60F-0H attained the lowest strength with 17.39 MPa. HDPE as fine aggregate replacement slightly increased or did not have a significant effect on the strength.

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