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RESISTIVITY AGAINST SULFATE ATTACK OF CONCRETE WITH HDPE AS PARTIAL SUBSTITUTE FOR FINE AGGREGATES

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ABSTRACT: High-Density Polyethylene (HDPE) when used as partial substitute of fine aggregates in concrete is investigated to determine if it addresses sulfate attack in concrete. Since HDPE is known to be resistant against chemical compounds including sodium sulfate, it is hypothesized in this study that sulfate attack problems in concrete will be lessened by incorporating HDPE in concrete mix. Mechanical properties of concrete were determined to ensure that HDPE is limited to an amount where there will be no serious compromise to strength, hence, compressive, and split tensile test are included in the study. To determine the influence of HDPE in addressing sulfate attacks, length change of mortar specimen is investigated using ASTM C1012 (length change of mortar exposed to sulfate solution). Scanning Electron Microscopy (SEM) is also employed to qualitatively assess the microstructure of concrete with HDPE exposed to sulfate attacks. Mechanical test results showed that increasing HDPE did not adversely affect the compressive strength. However, there was a decrease observed in tensile strength. To achieve balance between mechanical properties, HDPE replacement of fine aggregates was set at 10% by weight of fine aggregates. The mortar bar test demonstrated that increasing HDPE resulted to an increased resistivity against sulfate attacks. SEM have also shown reduction in voids and ettringite with increasing HDPE content..

Keywords: HDPE in concrete, Sulfate attack, Mortar bar test, Ettringite, Concrete resistivity

1. INTRODUCTION

Among the causes of deterioration in concrete is sulfate attack [1]. In coastal regions, sulfates from groundwater seeps through the pores in concrete and reacts with cement mix. These sulfate ions react with aluminates in concrete which forms gypsum and ettringite that causes concrete expansion [2]. ACI's Guide to Durable Concrete [3] mentioned that formation of gypsum and formation of ettringite are the two mechanisms that can be considered to be sulfate attack. Reactions, due to these two, results to damages in concrete due to increases in overall solid volume [4].

Concrete exposed to environment with high sulfate compounds are vulnerable to sulfate attack and so are concrete in contact with soil abundant with sulfate contents. Ground water and soils are considered to be the primary sources of external sulfates [4]. Aggregates may also contain sulfuric compounds that may initiate sulfate attacks if such aggregates are used in the production of concrete. Cement may also be a source of sulfate which can lead to internal sulfate attack.

Philippines is underlain by extensive groundwater reservoir which covers about 50,000 square kilometers [5]. Four major groundwater reservoirs in the Philippines are in Cagayan, Central Luzon, Agusan, and Cotabato. Many of the infrastructure development in the country are concentrated in Central Luzon, particularly in Metro Manila region. Hence, many of these structures will be potentially affected by sulfate attack. Sulfate attack is a potential problem in concrete hence, it must be addressed.

Sulfate attack may be caused externally, when sulfate-containing water seeps through concrete, or internally, when sulfate-rich aggregates are used. When sulfate ions react with aluminates in concrete, ettringite and gypsum are formed. These two cause a reaction that involves cracking, expansion, loss of bond between cement paste and aggregates, and/or alteration of paste composition. When cement paste is altered, monosulfate is converted into ettringite then into gypsum [3]. This takes up calcium from CaOH and CSH hence affecting the mechanical properties of concrete [4]. Consequently, the formation of ettringite causes expansion and cracking in concrete [4].

Other than contributing to helping save the environment by utilizing waste materials such as HDPE, high density polyethylene (HDPE) has been shown to have combative properties against sulfate attacks. ISO 10358 [6] stated that HDPE possesses higher chemical resistance compared to other polymers, particularly against sulfuric acid. Polymer impregnation was also shown to enhance the chemical resistance of concrete [7]. HDPE are plastics made up of polymer molecules linked together. Hence, when used in concrete as partial substitute for aggregates, HDPE has the potential to lessen the deterioration due to sulfate attacks.

Table 1. Concrete design mix (as per ACI 211.1)

Component (kg)	00HDPE	05HDPE	10HDPE	15HDPE	20HDPE
Water	205.00	205.00	205.00	205.00	205.00
Cement	379.63	379.63	379.63	379.63	379.63
Coarse Aggregates	1009.20	1009.20	1009.20	1009.20	1009.20
Fine Aggregates	691.30	656.73	622.17	587.60	553.04
HDPE	0.00	11.80	23.60	35.30	47.20

Table 2. Average compression and split tension strength (in MPa) of samples exposed to sulfate solution

% HDPE	Compression (MPa)		% reduction (pre to post-sulfate)	Tension (MPa)		% reduction (pre to post-sulfate)
	Pre-Sulfate	Post-Sulfate		Pre-Sulfate	Post-Sulfate	
00HDPE	36.43	32.45	11.0%	2.37	2.05	13.5%
05HDPE	39.15	37.80	3.4%	2.31	2.16	6.5%
10HDPE	35.53	34.66	2.4%	2.27	2.21	2.7%
15HDPE	44.48	40.11	9.8%	2.21	2.18	1.3%
20HDPE	42.36	41.07	3.0%	2.17	2.14	1.3%

Study of [8] used PET bottles as component of concrete and had shown that the reduction brought by sulfuric acid to crushing load, and weight loss, was lessened. Moreover, [9] showed that the use of PET as aggregates in concrete improved acid resistance of concrete. And [10] employed HDPE as coarse aggregates replacement in concrete and showed that with 10% and 20% replacement, compressive strength is comparable to that of normal concrete. M

This study investigated the impact of using HDPE in concrete in combating the effects of sulfate attacks in concrete using mortar-bar test (ASTM C1012) to determine length change, and spectron electron microscopy (SEM) to have a qualitative view of what happens in micro scale. Additionally, it will seek to establish the desirable amount of HDPE as partial replacement of fine aggregates in concrete without compromising the mechanical properties.

2. MATERIALS AND METHODS

The HDPE used in this study was in pelletized form bought commercially. To determine its suitability as a fine aggregate material, HDPEs were sieved using sieve No. 4. Only those that passed through sieve No. 4 were considered in the study. It has a specific gravity of 0.80, as provided by the supplier. Coarse and fine aggregates were sourced from a local hardware store. Upon checking experimentally (ASTM C127 and C128), [11,12] the specific gravities of fine aggregates and coarse aggregates are 2.34, and 2.81 respectively. Type I Portland cement was utilized in the preparation and making of concrete in this research. It is essential that Type I cement is used for this study because literatures that served as conceptual and theoretical basis for this study has utilized Type I cement. Their results had offered significant contribution in crafting the conclusion of this study hence to align the results of this study, type I cement was used. Utilization of HDPE as fine aggregates substitute were done in 5% to 20% by weight at 5% interval. Labelling of concrete mix was made based on amount of HDPE in the mix, e.g. 00HDPE means a concrete mix with no HDPE (control) and 005HDPE means a concrete with 5% HDPE by weight as partial replacement of fine aggregates. Table 1 shows the various concrete mixes used in the study.

2.1 Concrete Strength Test

Compression and tensile strength tests were done in accordance with ASTM C39 [13] and ASTM C496 [14]. Cylinders of size 100mm x 200mm were used, both for compression and split tension test. For all tests, three (3) specimens were prepared for each mix proportion. Five (5) mix proportions were prepared based on varying HDPE content as previously discussed in two sample sets: pre-sulfate samples, and post-sulfate samples. Pre-sulfate set were cured in water for 28 days while the post-sulfate set were cured in water for 28 days then cured for additional 28 days in sulfate solution

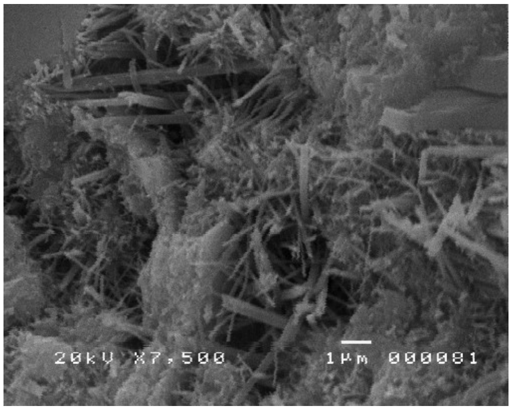

Fig.1 SEM of mortar with 0% HDPE (00HDPE)

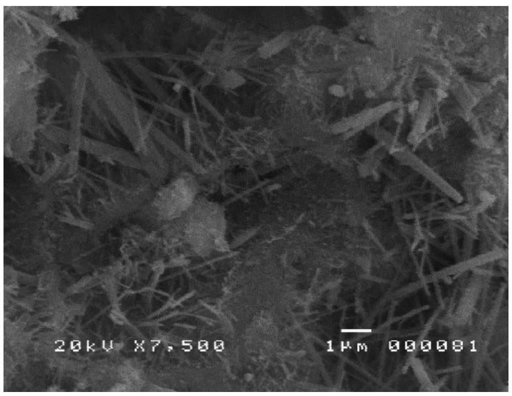

Fig. 2 SEM of mortar with 5% HDPE (05HDPE)

to simulate sulfate attack in concrete. The sulfate solution was prepared with 50 grams of Na_2SO_4 in 1 liter of water. After curing, specimens were tested for compression and tension. Concrete mix design was made in accordance with ACI 211.1 [15] and the design mix is shown in Table 1.

2.2 Mortar Test For Length Change

The mortar bar test involves measurement of length change of mortar specimens in accordance with ASTM C1012 [16]. Three mortar specimens, in rectangular prism of size 25mm x 25mm x 285mm, were prepared in varying HDPE content, from 0% to 20% at 5% interval. Each mix proportion was prepared with 3 specimens. Curing was made by immersion in water for 28 days then in sulfate solution for additional 28 days. Initial length reading was done before curing the specimen to sodium sulfate solution. Measurement of final length change was conducted after 28 days of curing in sulfate solution. Mortar mix was designed in accordance with ASTM C305 [17].

3. DATA AND ANALYSIS

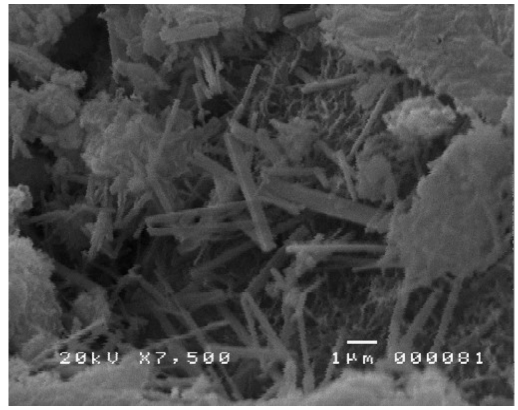

Fig. 3 SEM of mortar with 10% HDPE (10HDPE)

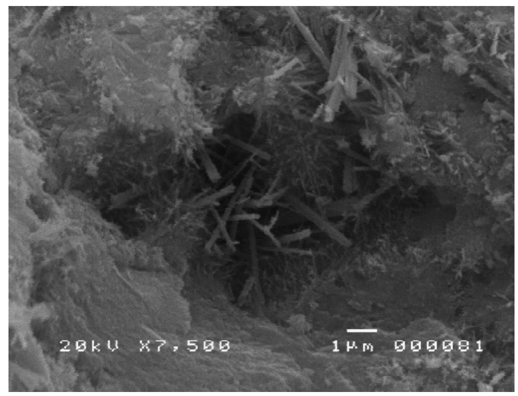

Fig. 4 SEM of mortar with 15% HDPE (15HDPE)

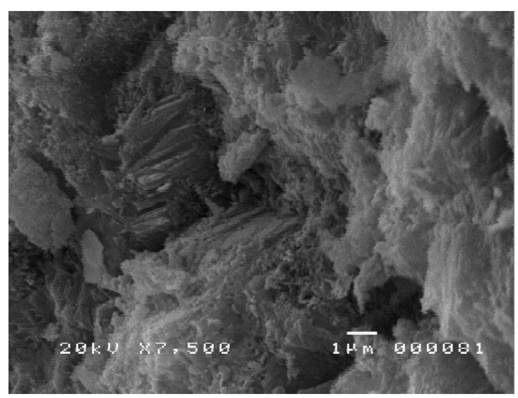

Fig. 5 SEM of mortar with 20% HDPE (20HDPE)

3.1 Strength Test Results

The result of strength tests for compression and tension is presented in Table 2. Reduction in strength is observed in all concrete exposed to sulfate solution (post-sulfate samples) regardless whether the concrete specimens had HDPE or not. This reduction in strength was not observed in all samples that were not exposed to sulfate solution. As mentioned earlier, the formation of gypsum during sulfate attacks takes up calcium from hydration products (i.e. CaOH and CSH) in hardened cement paste. Taking away calcium which is supposed to participate in hydration affects the development of strength of concrete negatively. It can also be observed from test results that for both compression and tension tests, these drops in strength caused by exposure to sulfate solution decrease as amount of HDPE in concrete mix increases. Compared to control sample, post-sulfate samples have demonstrated an increase in strength properties, both in compression and tension, as amount of HDPE in concrete increases. Additionally, all samples except 10HDPE compression samples, had demonstrated higher strength compared to samples with no HDPE (00HDPE). In summary, this study was able to observe experimentally that exposure to sulfate solution of concrete resulted to reduction in strength, that concrete with HDPE is capable of reducing the negative effect of sulfate solution in concrete strength, and finally, the addition of HDPE in concrete also contributes to the development/increase in strength.

3.2 Mortar bar test results

After immersing mortar bar samples to sulfate solution for 28 days, the final length is measured using a length comparator. Table 3 shows the average length change per mix. Mortar mixes includes a control sample (i.e. 00HDPE) and mixes with varying HDPE from 5 to 20% at 5% interval.

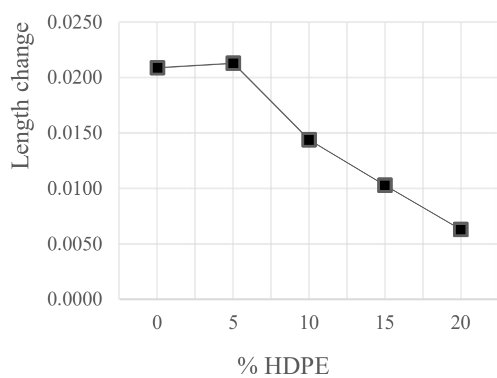

Fig. 6 Length change in mortar with varying HDPE

It is observed from this test that HDPE influenced the resistance of mortar bar specimens against length expansion attributed to sulfate attack. Summary of observations from this test (Fig. 6) showed a decreasing pattern in length change as amount of HDPE in mortar sample increases. This result supported the hypothesis of the study that HDPE, when mixed into concrete, will provide resistance against sulfate attacks and an increasing amount of HDPE will provide an increasing resistance against length change attributed to sulfate attacks.

Table 3. Length change of mortar bars

% HDPE	Average length change
00HDPE	0.0209
05HDPE	0.0213
10HDPE	0.0144
15HDPE	0.0103
20HDPE	0.0063

3.3 Spectron Electron Microscopy

As mentioned, sulfate attack in concrete happens when sulfate ions react with aluminates to form ettringite and gypsum which are responsible for concrete expansion leading to cracking. This study attempted to look for the formation of ettringite after exposing concrete specimens to sulfate solution for 28 days. Formation of ettringites are expected to be more common on areas with wide spaces, like cracks and voids, as the formation of ettringite crystals require space. Figures 1 to 5 show ettringite formation (needle-like crystals in the micrographs) typically along the void regions. These micrographs also exhibited decreasing amount of ettringite formation with increasing HDPE amount. It can also be noticed that voids were reduced with increasing HDPE.

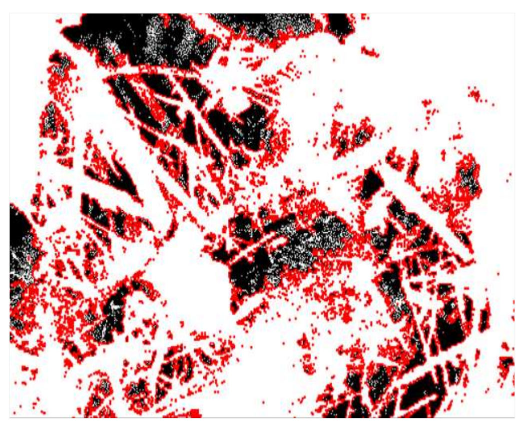

Fig. 7 A sample imageJ conversion of an SEM image (i.e. SEM of 05HDPE)

These micrographs support the results of length expansion by mortar bar test which implies that increasing HDPE contributes to the reduction of ettringite and correspondingly, reduction in voids and size resulting to reduced length expansion as shown by mortar bar tests.

Table 4. Computation of ettringite and void area using ImageJ

% HDPE	Ettringite Area (μm^2)	Void area (μm^2)
00HDPE	91.962	23.689
05HDPE	113.345	37.646
10HDPE	74.306	8.883
15HDPE	37.731	6.668
20HDPE	10.184	4.680

Using ImageJ, a platform for processing scientific images, quantification of area of ettringite and voids from SEM images were computed and summarized in Table 4. This table provided quantification supporting the study claim that SEM results showed reduction in the amount of ettringite and voids as a consequence of increasing HDPE in concrete. Figures 7 was a sample ImageJ reduction of SEM image to be able to quantify areas of voids. Images in black are the voids while red spots mark the boundaries. Similar procedure was done to calculate the ettringite areas. Ettringite and voids calculation show that with increasing HDPE, both areas of ettringite and voids decreases.

4. CONCLUSION

In order to address the potential deterioration that can be brought about by sulfate attacks in concrete, the use of HDPE in concrete was explored. HDPE is known to be capable of resisting various chemical reactions including sulfate. This study investigated the mechanical properties of concrete with varying HDPE used as partial substitute for fine aggregates enable to check if utilization of HDPE in concrete compromises strength. Concrete mix with 5% to 20% HDPE at 5% interval were investigated. Based on experimental results, HDPE significantly reduces the tensile strength of concrete but showed no adverse impact in compressive strength. Increase in compressive strength were even observed in samples containing 5%, 15% and 20% HDPE. Exposure to sulfate solution, to simulate sulfate attacks, clearly revealed that both compressive and tensile strength properties decreased. However, with HDPE in increasing amounts, this reduction in strength was lessened. This showed the potential of HDPE to arrest the negative impact of sulfate attacks in concrete.

Length change of mortar bars exposed to sulfate solution were also evaluated in this study. The change in length, as a result of exposure to sulfate solution, decreases as the amount of HDPE increases. To verify this further, SEM images of concrete samples with varying HDPE were taken. From SEM micrographs, the formation of ettringite and development of voids (or cracks) in concrete have decreased with increasing HDPE. These are significant demonstration of HDPE providing resistance against sulfate attacks.

5. ACKNOWLEDGMENTS

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