# EFFECT OF GRAPHENE NANOPLATELETS ON MECHANICAL PROPERTIES OF HIGH-VOLUME FLY ASH CONCRETE CONTAINING PLASTIC WASTE

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*ABSTRACT*

Plastic wastes have been increasing every year due to the high demands of plastic use in many applications. This is one of the important environmental problems and leads to the challenge issue on waste management. Attempts have been made to reuse and/or recycle of plastic wastes by applying in construction. An idea on use of plastic waste in concrete as partial replacement to fine or coarse aggregate has been introduced. However, the major setback on using plastic waste in concrete is its negative effect on the mechanical and durability performance of concrete. This study aims to use graphene nanoplatelets (GNP) as an additive in order to mitigate the negative effect of plastic waste in concrete. 40% fly ash replacement by volume of cement was used in this study. Plastic waste was used to partially replace coarse aggregate in concrete mix at 30% by volume, and GNP was added at 0%, 0.15%, and 0.30% by weight of cementitious materials. Four mixes were prepared and tested for compressive strength, splitting tensile strength, and flexural strength at 3, 7, and 28 days of curing. The results showed that GNP can partially reduce the loss in strengths in concrete due to negative effect of plastic waste, as the mixes with GNP showed higher strengths compared to those without GNP. In conclusion, GNP can effectively enhance the mechanical properties of concrete containing plastic waste for structural applications.

***Keywords:*** *Fly Ash, Plastic Waste, Graphene Nanoplatelets, Compressive Strength, Splitting Tensile Strength, Flexural Strength.*

## 1. INTRODUCTION

Plastic waste had been used in concrete as partial replacement to fine or coarse aggregate [1-2]. The use of recycled plastic waste has been explored as an efficient way of improving concrete and mortar properties for specific applications [3]. For instance, concrete with recycled plastic waste as aggregate showed excellent ductility in the post-crack region and flexural toughness of concrete [4]. Furthermore, plastic waste can effectively reduce the density and the brittleness of concrete and mortar and demonstrates good performance in thermal insulation [5-7]. However, plastic waste decreases the strengths and durability performance of concrete.

Graphene nanoplatelets (GNP) was used as an additive by weight of cementitious materials in order to partially or fully mitigate the negative effects of plastic waste on the mechanical and durability performance of concrete. The recent studies have demonstrated that GNP can be used as a promising nano-sized additive to improve the mechanical properties and durability performances of cement composites [8]. According to this approach, GNP is then selected as a participant for this study. However, GNP is added in very small amount to cementitious composites due to its high reactivity and high cost. To reduce the cost of concrete when graphene nanoplatelets is added, high-volume fly ash (HVFA) will be used to partially replace cement.

Consequently, the purpose of this research is to develop a sustainable high-volume fly ash (HVFA) concrete using plastic waste and graphene nanoplatelets (GNP). In addition, the effect of GNP content on the mechanical properties of concrete including compressive strength, splitting tensile strength, and flexural strength have been investigated.

## 2. EXPERIMENTAL PROGRAM

### *2.1. MATERIALS*

#### *2.1.1. CEMENT*

The Ordinary Portland Cement (OPC) Type I conformed to ASTM C150M-20 [9] was used. Physical and chemical properties of OPC are summarized in Table 1.

Table 1 Properties of cement and fly ash

| Chemical composition (%) | Cement | Fly ash |
|---|---|---|
| $SiO_2$ | 17.8 | 42.4 |
| $Al_2O_3$ | 4.29 | 21.3 |
| $Fe_2O_3$ | 2.97 | 13.2 |
| CaO | 61.1 | 15.7 |
| MgO | 0.87 | 2.3 |
| $Na_2O$ | 0.34 | 0.9 |
| $K_2O$ | 0.26 | 2.0 |
| $TiO_2$ | 0.22 | 0.5 |
| $P_2O_5$ | - | 0.2 |
| MnO | - | 0.1 |
| $SO_3$ | 4.14 | 1.0 |
| LOI | 1.9 | 0.4 |
| Specific surface area ($m^2$/kg) | 376 | 363 |
| Specific gravity | 3.15 | 2.54 |

#### *2.1.2. HIGH-VOLUME FLY ASH (HVFA)*

High-volume class C fly ash conformed to ASTM C618-19 [10], and the particles are formed in spherical shape with specific gravity of 2.54, was used as supplementary cementitious materials (SCM). X-ray fluorescence (XRF) analysis was used to determine the chemical properties of the fly ash as shown in Table 1.

#### *2.1.3. AGGREGATES*

Well-graded natural river sand conforming to the requirements of ASTM C33-03 [11] in saturated surface dried form was used as a fine aggregate. The aggregate has a specific gravity and fineness modulus of 2.64 and 2.80, respectively. The particle size distribution of the natural river sand, as obtained using ASTM C136 [12], is shown in Figure 1.

A well graded gravel with nominal maximum size aggregate (NMSA) of 19 mm was used as a coarse aggregate. Particle size gradation of the gravel is shown in Figure 2. The specific gravity (SSD) of the used coarse aggregate is 2.67.

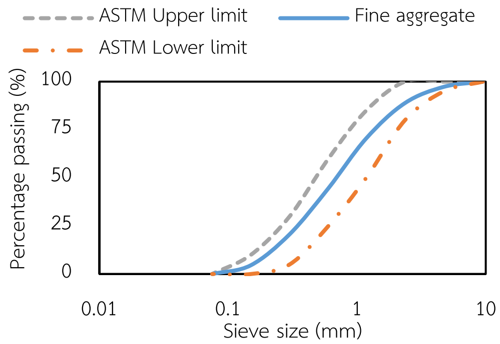


Figure 1. Particle size analysis of fine aggregate

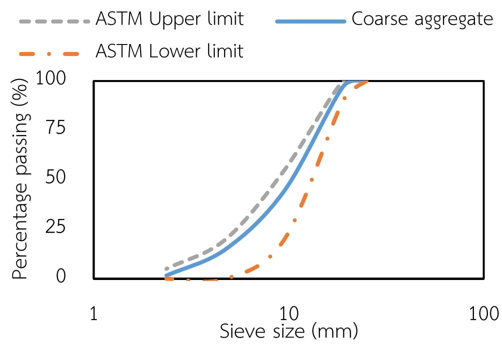


Figure 2. Particle size analysis of coarse aggregate

#### *2.1.4. PLASTIC WASTE*

Two sizes of polypropylene plastic waste (see Figure 3) obtained from Grand Siam Composites Company were used in this study. Aggregate size of the light substance and the dark substance is 12.70 mm and 9.525 mm, respectively.

Figure 3. Plastic Waste

#### *2.1.5. GRAPHENE NANOPLATELETS (GNP)*

Graphene nanoplatelets in black or grey powdered form were obtained from ACS Materials LLC, Canada, as shown in Figure 4. The physical and chemical properties of the GNP is presented in Table 2.

Figure 4. Graphene nanoplatelets (GNP)

Table 2. Properties of GNP

| Properties | Values |
|---|---|
| Diameter (μm) | 2 - 7 |
| Thickness (nm) | 2 – 10 |
| Specific surface area ($m^2/g$) | 16.48 |
| Electrical conductivity (S/m) | 80000 |
| Carbon content (%) | > 99 |
| Apparent density (g/ml) | 0.06 – 0.09 |
| Water content (wt.%) | < 2 |
| Weighted residual (wt.%) | 0.2 |
| Concentration (%) | 0.25 |
| Uniformity | 0.52 |

#### *2.1.6. SUPERPLASTICIZER*

A high performance polycarboxylate-based superplasticizer, trade named as Sika ViscoCrete-10 TH, was used as a high-range water reducing admixture. The solution was prepared in form of light brownish liquid, free from chloride with a pH of 4.97 and a density of 1.060 $g/cm^3$. The superplasticizer was used together with mixing water to disperse effectively the GNP for avoiding agglomeration. The solution was added at 1% by weight of cementitious materials.

### *2.2. MIX PROPORTIONS AND CASTING*

#### *2.2.1. MIXTURE PROPORTIONS*

The control concrete mix (0% plastic waste, 0% fly ash, and 0% GNP) was designed in accordance with the guidance suggested in ACI 211.1-91 [13]. The mixture was prepared for a target design characteristic strength of 30 MPa., i.e., cube strength of 37 MPa at 28 days, using a nominal maximum size aggregate of 19 mm, and a constant water-to-cement ratio of 0.45. The quantities of materials for the control mix are shown in Table 3.

For remaining mixtures, fly ash was used at 40% replacement by volume of cement. Plastic waste was used to partially replace coarse aggregate at 30%. GNP was added at 0%, 0.15%, and 0.30% by weight of cementitious materials.

#### *2.2.2. PREPARATION AND CASTING OF SPECIMEN*

The molds sizes include 100 mm × 100 mm × 100 mm cubes, 100 mm diameter × 200 mm height cylinders, and 100 mm × 100 mm × 350 mm prisms. The fresh concrete samples were poured into the designated steel molds depending on the sample size. This procedure was done in accordance with ASTM C192/192M [14]. The molds were cleaned, tightened, and oiled properly before casting. The molds were filled in three layers, with each layer fully compacted using concrete vibration before the next layer was poured. After filling the molds, the top surface was screed off and excess concrete was removed, then hand trowel was used to achieve a smooth finishing. For each mixture, three samples were prepared. The samples were removed from the molds after 24 hours and cured in water.

Table 3. Concrete mix proportions

| Mix | PW (%) | HVFA (%) | GNP (%) | Cement ($kg/m^3$) | HVFA ($kg/m^3$) | Fine Agg. ($kg/m^3$) | Coarse Agg. ($kg/m^3$) | PW ($kg/m^3$) | GNP ($kg/m^3$) | Water ($kg/m^3$) | S.P. ($kg/m^3$) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| P0-F0-G0 | 0 | 0 | 0 | 420.7 | 0 | 653.9 | 1176.9 | 0 | 0 | 159.4 | 4.21 |
| P30-F40-G0 | 30 | 40 | 0 | 252.4 | 122.9 | 653.9 | 823.8 | 43.7 | 0 | 159.4 | 3.75 |
| P30-F40-G0.15 | 30 | 40 | 0.15 | 252.4 | 122.9 | 653.9 | 823.8 | 43.7 | 0.56 | 159.4 | 3.75 |
| P30-F40-G0.30 | 30 | 40 | 0.30 | 252.4 | 122.9 | 653.9 | 823.8 | 43.7 | 1.13 | 159.4 | 3.75 |

### *2.3. TEST METHOD*

#### *2.3.1. COMPRESSIVE STRENGTH TEST*

The compressive strength of the concrete was done in accordance with BS 12390-3:2009 [15] using 100 mm cubes. The test was carried out using a 3000 KN. Universal testing machine (UTM). For each mixture, the compressive strength was determined after 3, 7, and 28 days curing periods. Three samples were prepared for each mixture. The average results at each curing period were collected.

#### *2.3.2. SPLITTING TENSILE STRENGTH TEST*

The splitting tensile strength test was used to measure the indirect tensile strength of the concrete. The test was carried in accordance with the guidance of BS EN 12390-6:2009 [16] using cylindrical samples of 100 mm diameter and 200 mm height. For each mixture, the splitting testing strength was determined after 3, 7, and 28 days curing periods. Three samples were prepared for each mixture. The average results at each curing period were also reported.

#### *2.3.3. FLEXURAL STRENGTH TEST*

The flexural strength, obtained from the rectangular-shaped specimens of sizes 100 mm × 100 mm × 350 mm, was determined in accordance with the guidance of ASTM C78. The flexural strength was measured by considering the curing period of 7 and 28 days. For each mixture and curing period, three samples were prepared and tested, the average value were then recorded.

## 3. RESULTS AND DISCUSSION

### *3.1. COMPRESSIVE STRENGTH*

The results of the compressive strength are shown in Figure 5. The compressive strengths of control mix (P0-F0-G0) were 20.82 MPa, 27.64 MPa, and 37.81 MPa for the curing age of 3, 7, and 28 days, respectively. However, when 30% of plastic waste and 40% of fly ash were added (P30-F40-G0), the compressive strength of the concrete decreased by approximately 20.55% compared to the control mix. The compressive strengths of specimen P30-F40-G0 at 3-day, 7-day, and 28-day were 19.05 MPa, 22.72 MPa, and 26.77 MPa, respectively.

However, when GNP was added to the concrete specimen, the compressive strength of the concrete specimen increased. By adding 0.15% of GNP (P30-F40-G0.15), the compressive strengths at 3, 7, and 28 days enhanced to 21.34 MPa, 23.48 MPa, and 27.35 MPa, respectively. In addition, by adding 0.3% GNP (P30-F40-G0.30), the compressive strengths were 25.98 MPa, 29.35 MPa, and 35.20 MPa, for 3-, 7-, and 28-day age, respectively. It is found that the compressive strengths of P30-F40-G0.30 was almost the same with those of the control mix (P0-F0-G0).

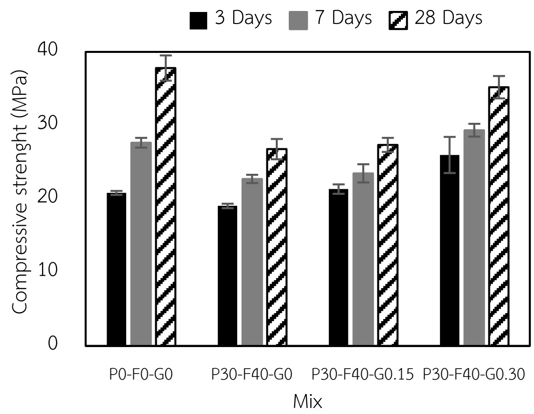


Figure 5. Compressive strength at 3, 7, and 28 days.

### *3.2. SPLITTING TENSILE STRENGTH*

The result for splitting tensile strength of concrete mixtures was determined at the ages of 3, 7, and 28 days. Results are shown in Figure 6. From the result, it was found that the P30-F40-G0 concrete specimens containing 30% of plastic waste and 40% of fly ash replacement with a curing age of 3, 7, and 28 days have a splitting tensile strengths of 1.36 MPa, 1.75 MPa, and 2.16 MPa, respectively, which had a lower splitting tensile strength than those of regular concrete or control mix (P0-F0-G0), which had splitting tensile strengths at curing ages of 3, 7, and 28 days of 2.06 MPa, 2.40 MPa, and 3.32 MPa, respectively.

For the case of adding GNP to the specimen, it is noted that the use of GNP significantly increased the splitting tensile strength of concrete specimen. When only 0.15% GNP was added, the splitting tensile strengths of concrete specimens were increased to 2.18 MPa, 2.34 MPa, and 3.04 MPa, respectively. For the case that the addition of GNP was up to 0.30%, the splitting tensile strengths of concrete specimens increased to 2.27 MPa, 2.77 MPa, and 3.65 MPa respectively, as shown in Figure 6. When compared with the P30-F40-G0 concrete specimen with 30% of plastic added, 40% of fly ash replacement, and without additive GNP, it was seen that the 0.30% GNP enhanced the splitting tensile strength of concrete by approximately 64.81%.

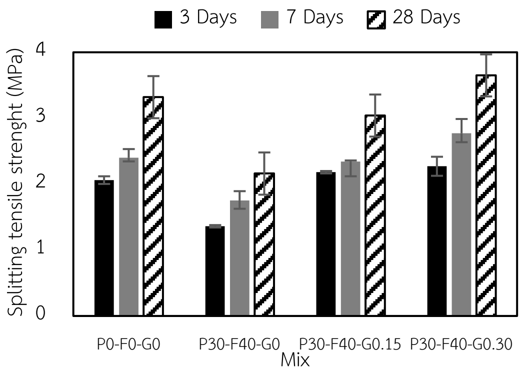


Figure 6. Splitting tensile strength at 3, 7, and 28 days

### 3.3. *FLEXURAL STRENGTH*

For the flexural strength of concrete, the results in Figure 7 showed that P30-F40-G0 achieved the flexural strength of 6.04 MPa and 7.08 MPa at the curing period of 7 and 28 days, respectively. The obtained flexural strengths were lower than those of the control mix (P0-F0-G0) that offered the flexural strength of 7.33 MPa at 7 days and 8.31 MPa at 28 days. Using 30% of plastic and 40% of fly ash decreased the flexural strength of concrete by approximately 17.6% at 7 day and 14.7% at 28 day.

However, when only 0.15% of GNP was added to concrete (P30-F40-G0.15), the flexural strengths increased to 6.60 MPa at 7 days and 7.12 MPa at 28 days, as shown in Figure 7. Moreover, when the amount of GNP was increased to 0.30%, the flexural strengths of concrete increased to 6.97 MPa at 7 days and 8.01 MPa at 28 days. Therefore, it can be seen that adding 0.30% of GNP to concrete specimens containing with 30% plastics and 40% fly ash can increase the flexural strength of concrete approximately 15.34% and 13.09% for the curing period of 7 and 28 days, respectively.

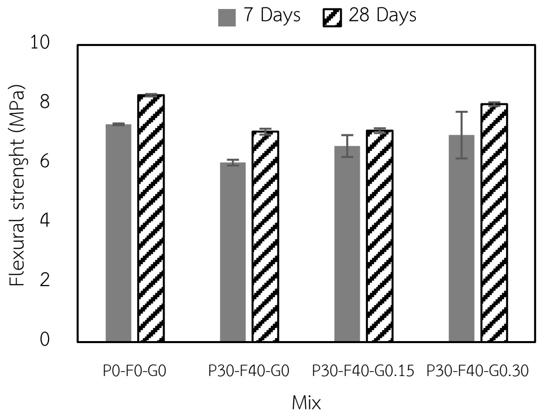


Figure 7. Flexural strength at curing age of 7 and 28 days

## 4. CONCLUSIONS

Based on the experimental results, the following conclusions were drawn:

1) The partial replacement of coarse aggregate with plastic waste significantly decreased the compressive strength, splitting tensile strength, and flexural strength of HVFA concrete.
2) Partial replacement of cement with HVFA further decreased the compressive strength, splitting tensile strength, and flexural strength of the concrete.
3) Adding GNP as an additive by weight of cementitious materials can improve the compressive strength, splitting tensile strength, and flexural strength of HVFA concrete containing plastic waste.

## 5. ACKNOWLEDGMENTS

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