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# LOW CARBON CONCRETE: CEMENT REPLACEMENT UTILIZING FLY ASH

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**ABSTRACT**

Reducing the cement content in concrete is the need for environmental sustainability, as cement produces a significant carbon emission. This work aims to study the effect of partial replacement of the cement utilizing fly ash at the various percentage of substitution by investigating the physical characteristic of concrete ingredients, compressive testing at various curing age, workability, and material cost reduction. Fly ash used in this research is categorized as type F, which obtained from Jepara powerplant. Along with fly ash, ordinary pozzolan cement (OPC) from Semen Gresik used as binder material. The fine and coarse aggregates quarried consecutively from Magelang Regency and Kulon Progo Regency, Indonesia. All the constitutes being observed on specific gravity, gradation test, clay lumps content, and abrasion resistance. The job mix formula developed adopting Indonesian Standard based on the physical data obtained previously, resulting in five levels of cement replacement which is 0%, 15%,20%, 25%, and 30% compared to cementitious weight. Concrete cylinder specimen having 150 mm on the diameter and length of 300 mm, tested at various age (7,14, and 28 days) to obtained compressive strength and strength development during curing age. The current works remarks that all level of replacement obtained a good agreement with targeted compressive strength (25 MPa) at the age of 14 days. However, the more fly ash supplemented in the mixture, strength development possesses a slower rate and a slight declining on workability. Eventhough the slump value still comply with the requirement given by the Indonesian Standard.

***Keyword:*** *Fly ash, cement, strength.*

## I. INTRODUCTION

Concrete has been known as a remarkable material as its high compressive strength, durable, and environmentally low impact compared to steel (Struble and Godfrey, 2006). The number of concrete used worldwide reach an enormous volume, about 12 billion tonnes/year (Domone and Illston, 2010). However, due to its immense volume used in construction, environmental impact arises as to the main issue on concrete utilization. The issue involving land use implication as aggregates quarrying and carbon emissions of cement manufacturing (Humprey and Mahasenan, 2002). It is recorded that 5 % of world carbon emissions ($CO_2$) caused by cement industries (Flower and Sanjayan, 2007). The previous study also reveals that cement manufacturing process is the highest contributing factor (88 %) on carbon footprint every tonne produced concrete. Furthermore, the remaining 12% is contributed by other factors such as aggregate production, concrete production, and transportation (Fig.1) (Prusinski et al., 2006). Hence, this is a sharp reason to develop a greener concrete that has a better environmental impact; in this case, lower carbon emission.

According to the consideration aforementioned, this paper focused on the investigation of how the partial cement replacement using fly ash affecting several concrete parameters on normal concrete (targeted f'c of 25 MPa). Slump, compressive strength, volume weight, and material cost are observed to understand the performance of lower carbon concrete (with fly ash substitution) compared to the conventional one (without fly ash).

## II. LITERATURE REVIEW

In order to reduce the carbon emitted by concrete making, several techniques could be used, such as cement replacement, manufacturing energy efficiency, and reducing natural material extraction (US concrete, 2019). Because cement manufacturing classified as the most significant contributors, cement replacement becomes the most reasonable step to cut off the carbon emission instantly. It is expected that by reducing the level of cement usage, the carbon emissions generated will also decrease. However, reducing the volume of cement results in a sharp reduction in concrete compressive strength (CIF, 2003).

Therefore, cement volume decrease must be accompanied by the addition of admixture material with pozzolanic properties. Pozzolanic is a material containing aluminum or silica-aluminum which react with calcium hydroxide at a specific temperature producing cementitious compounds as a binder (Black, 2016; Tillman et al., 2012). Remarkable materials that categorized as pozzolanic are fly-ash, metakaolin, nano-silica, silica-fume, calcium hydroxide, and slag (Sims and Brown, 1998). Previous research also proves that the use of pozzolanic material successfully reduces a carbon footprint up to 23-55% lower than portland cement (Maddalena et al., 2018).

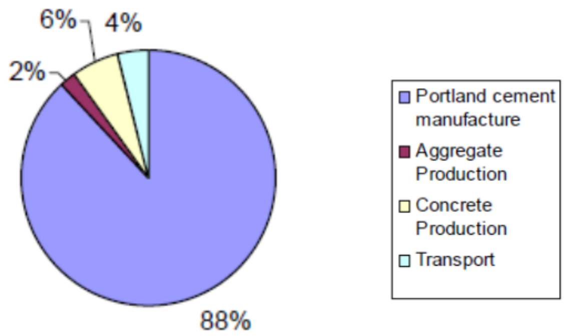


**Figure 1.** Contributing factors of carbon footprints of concrete (Prusinski et al., 2006)

Furthermore, material selection to be used in substitution and replacement depend on locally available materials. Meanwhile, in Indonesia, there is a potential supply of fly ash and bottom ash ranging from 2,7 million to 11,2 million tonnes/year as a by-product of the coal-powered plant (PLTU) that uses coal as fuel (Damayanti, 2018). Both types of ash having a possibility to be used by concrete industries for cementitious substitution material. In particular, the use of fly ash in Indonesia is more extensive than bottom ash. Generally, fly ash is available in the form of fine grains, which light, round, and non-porous (Damayanti, 2018). Fly ash has been used as cement replacement material at a broad level reaching 15% to 25% by mass of the cementitious material and presents considerably excellent mechanical properties and durability (Marceau et al., 2002).

The use of fly ash as a partial replacement for cement also presents positive effects, including increased workability and decreased bleeding in fresh concrete. This phenomenon is caused by the spherical shape and smooth surface of fly ash particles as opposed to angular cement particles. Despite many vast improvements in cost, workability, and environment impact of concrete, fly ash needed a longer setting time compared to portland cement (Bouzoubaa and Foo, 2005). Along with all the benefits and drawbacks of fly ash, Indonesian Standards (BSN, 2000) set a limitation on the quantity of fly ash (cementitious material) for structural concrete use, expressed as a percentage of the total cementitious materials by mass ranging from 15 to 25 % (F class) and 20-35% (C class).

## III. METHODOLOGY

To reveal the performance of the lower carbon concrete made from the partial replacement using fly ash, the experimental test conducted at PT. Varia Usaha Beton laboratory. Material that been employed in this research obtained locally; binder material of concrete utilizes ordinary portland cement (OPC type I) from PT. Semen Gresik along with fly-ash type F from the Jepara powerplant. Later, coarse aggregates obtained from Clereng while Merapi sand from Kali Putih, Magelang used as fine aggregates. The utilization of admixture (Naphtoplast and Plastiment) was introduced to improve the concrete compressive without neglecting the workability.The study started with material properties testing (gradation, specific gravity, and fineness modulus), followed by the calculation of mix design according to Indonesian Standard (BSN, 1990). Five variations of job mix formula involved 0 %, 15%, 20%, 25%, and 30% of fly ash content as an attempt to partially reduce the cement (Table 1). Furthermore, the concrete mixture made corresponding to the job mix formula tested by the slump test to evaluate the workability. The standard cylinder specimen with a diameter of 150 mm and 300 mm in length was made to assess the compressive parameter. The concrete cylinder examined using a universal testing machine (UTM) with the capacity of 2000 kN at the age of 7, 14, and 28 days, to learn the effect of fly ash on the setting time. Curing process of the concrete cylinder held by immersing the specimen into the water until the day before the test.

**Table 1.** specimens job mix formula

| Components | Job Mix Formula | | | | |
|---|---|---|---|---|---|
| | NFA | FA 15% | FA 20% | FA 25% | FA 30% |
| w/c ratio | 0.45 | 0.45 | 0.45 | 0.45 | 0.45 |
| Water (kg) | 185 | 185 | 185 | 185 | 185 |
| Cement (kg) | 409 | 348 | 327 | 307 | 287 |
| w/cm ratio | 0 | 0.15 | 0.20 | 0.25 | 0.30 |
| Fly ash (kg) | - | 61 | 82 | 102 | 123 |
| Fine aggregates (kg) | 816 | 798 | 798 | 798 | 798 |
| Coarse agg. (10-20 mm) (kg) | 598 | 609 | 609 | 609 | 609 |
| Coarse agg. (20-30 mm) (kg) | 399 | 399 | 399 | 399 | 399 |
| Additive Naphtoplast (litre) | 2.45 | 2.45 | 2.45 | 2.45 | 2.45 |
| Additive Plastiment (litre) | 1.02 | 1.02 | 1.02 | 1.02 | 1.02 |

## IV. RESULT AND DISCUSSION

### 4.1 Physical properties of aggregates & admixture

Physical properties test aimed to identify the character of the aggregates and other constitutes compared to the particular standard (ASTM, 2013; BSN, 1989) to examine whether the aggregate is suitable to be used in concrete production. The test consists of aggregates parameters, including fineness modulus, grain size, specific gravity, clay lumps, abrasion, and gradation test (Table 2 and Fig.2).

The test result in Table 2 explains that both fine and coarse aggregates completed the requirement to be used for normal concrete. Indonesian Standard (BSN, 1989) restricts the clay lumps content at the amount of maximum 1% for coarse aggregates and 5 % for fine aggregates, while both coarse and fine aggregates only contained 0.53 % and 4.9 % consecutively. Based on the gradation curve in Figure 2, the fine aggregates classified as medium sand (Zone II) in Indonesian Standard (BSN, 1989). Furthermore, the coarse aggregates present an excellent resistance to abrasion with Los Angeles value up to 22.4-22.9 %, whereas the limit from ASTM is about < 50% (ASTM, 2013). All the physical properties confirm that all the ingredients are suitable for concrete making.

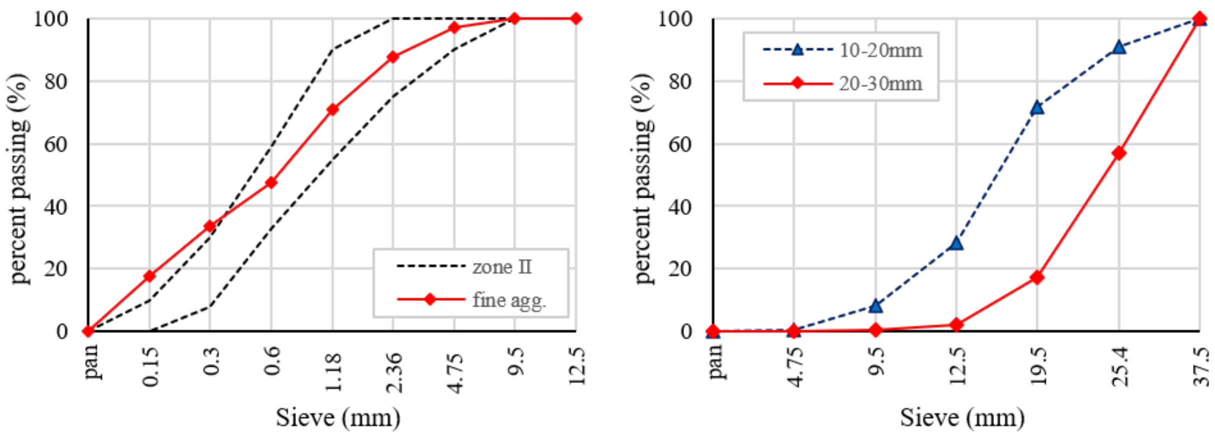


**Figure 2.** Gradation curve of (a) fine aggregates and (b) coarse aggregates

**Table 2.** specimens job mix formula

| Parameters | Fine aggregates | Coarse Aggregates | | Fly ash | Naphtoplast | Plastiment |
|---|---|---|---|---|---|---|
| | | 10-20 mm | 20-30 mm | | | |
| Fineness modulus | 2.46 | 8.00 | 9.22 | - | - | - |
| Clay lumps (%) | 4.90 | 0.53 | 0.53 | - | - | - |
| Bulk density (kg/m$^3$) | 1,443 | 1,345 | 1,345 | - | - | - |
| Water absorption (%) | 2.04 | 1.79 | 1.83 | - | - | - |
| Specific gravity | 2.70 | 2.68 | 2.69 | 2.68 | 1.15 | 1.09 |
| Los Angeles abrasion (%) | - | 22.4 | 22.9 | - | - | - |

## 4.2 Concrete volume weight and workability

As presented in Table 3, concrete volume weight varies linearly with the percentage of partial cement replacement with fly ash, ranging from 2,407 kg/m$^3$ (0 %, Non-fly ash) to 2,389 kg/m$^3$ (fly ash 30%). There is a positive relationship between the amount of fly ash with concrete weight volume; the increase of fly ash content made the concrete lighter. This phenomenon is caused by the specific gravity of fly ash is lower than cement. Therefore, it is an advantage, because the lighter the concrete, the structure will have a smaller dead load, which is a significant added value.

**Table 3.** Average volume weight and slump result

| Specimens | Average Compressive strength (MPa) | | | Average volume weight (kg/m$^3$) | Average slump (cm) |
|---|---|---|---|---|---|
| | 7 day | 14 day | 28 day | | |
| NFA | 24.54 | 31.11 | 33.56 | 2,407 | 12 |
| FA 15% | 23.24 | 28.80 | 32.40 | 2,398 | 12 |
| FA 20% | 22.73 | 28.00 | 32.40 | 2,395 | 11 |
| FA 25% | 22.59 | 28.51 | 31.97 | 2,392 | 11 |
| FA 30% | 19.05 | 25.12 | 27.64 | 2,389 | 10 |

The ease of concrete work (mixing, pouring, and casting) could be investigated from the slump value of fresh concrete. For the targeted compressive strength, Indonesian standard (BSN, 2013) limits that slump must be in a range between 6 to 18 cm. Furthermore, it is pointed out that the slump value decreased (from 12 to 10 cm) as the percentage of fly ash increased (Table 3), means that the addition of fly ash brings to slightly diminishing the workability. However, even the value is decreased, all of the specimens still meets the range given by Indonesian standard, perhaps it is not a significant obstacle.

## 4.3 Compressive strength development

Testing of compressive strength carried on when the specimens were 7, 14, and 28 days old, to understand the strength development and the setting time of concrete (Fig.3). As determined on the job mix formula, the desired concrete strength is 25 MPa which being a threshold to evaluate the strength of each percentage of cement replacement.

The result on Table 3 and Figure 5 explicates that the target (25 MPa) is accomplished by all variant (NFA to FA30%) after 14 days curing, with the result ranging from 31.11 to 25.12 MPa. This result means that cement replacement until the level of 30% fly ash still presents a good agreement with the target. However, the more fly ash used, the strength development slightly decreased by 19 % slower than non-fly ash (NFA). Confirmed by the previous researcher (Bouzoubaa and Foo, 2005), fly ash made the hydration reaction takes more times than conventional concrete. Furthermore, the strength continues to develop until 28 days with the strength reach 33.56 MPa (non-fly ash, NFA) and 27.64 MPa (30 % fly ash). This performance is an unexpected result, caused by the mix design only targeted at 25 MPa, which can be easily achieved by all variant (NFA to FA 30%).

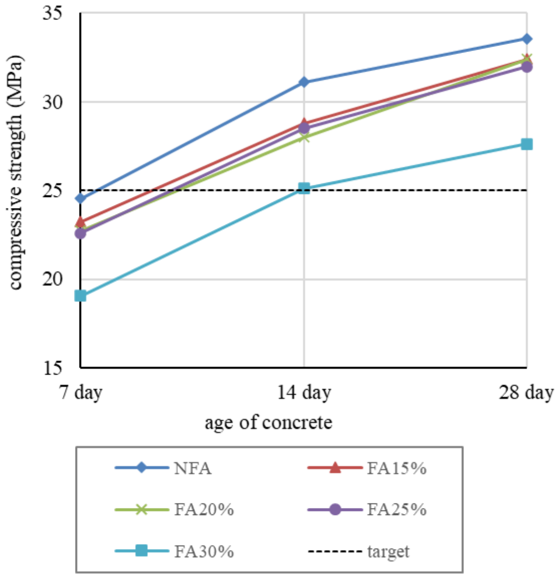


**Figure 3.** Compressive strength development

**Figure 4.** Concrete specimen after the test.

### 4.4 Material cost reduction

Thus, the replacement of cement content until the level of 30% proved that it could afford a considerably match with the targeted strength (25 MPa), with lower cement content reaching 30 % which also causes the carbon emission declined to 30% compared to conventional concrete. Moreover, from the economic aspect, this is also an added advantage that the cement replacement could cut down the production cost caused by the material (cement) cost. The result (Fig. 4) confirmed that the material cost could be cut down until 30% (for 30% fly ash content).

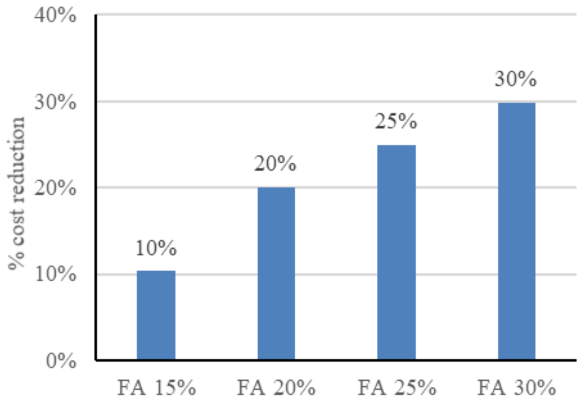


**Figure 5.** Material cost reduction

## V. CONCLUSION

This paper presents the partial cement replacement using fly ash that was experimentally examined based on Indonesian standard. According to the result of conducted experiments, the followings concluded The substitution of cement utilizing fly ash for normal concrete could be maximized until the level of 30% without neglecting the targeted compressive strength (25 MPa). The higher volume of fly ash used, the strength development at the age of 28 days considerably slower, ranging from 3% to 19 %, compared to conventional concrete. The addition of fly ash up to 30% from the cementitious weight, affect the workability insignificantly, even though the slump test indicated a slightly declining result. Without disregarding the strength requirements, economic benefits up to 30% from material cost could be accomplished by partial replacement of cement ranging from 15 to 30%.

## VI. ACKNOWLEDGEMENT

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