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Effects of different size of fly ash as cement replacement on selfcompacting concrete properties

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Abstract. This paper aims to investigate experimentally the influence of replacing cement with different fineness of fly ash based on flowability, passing ability, compressive strength, tensile strength (splitting). Concretes with 15% fly ash (passed a number 100 sieve) and fine fly ash (passed a number 200 sieve) as cement replacement were cast and tested at 7, 14, 28 days after water curing. A superplasticizer in the form of viscocrete 3115 N was constantly used for each concrete mixtures as much as 1% by weight of cement. The results show that the use of fly ash does not significantly increased the compressive strength and tensile strength of SCC mixtures. However, concrete with 15% fine fly ash its self and combined 7.5% fly ash with 7.5% fine fly ash show better flowability and passing ability when compared to concrete with cement only indicating the performance of using smaller particle sizes of fly ash could lead better properties of SCC that can be potentially used for building construction application.

Keywords : Self compacting concrete, superplasticizer, fly ash, viscocrete, compressive strength

1. Introduction

Concrete is the most widely used as structural materials today. In order to achieve concrete with great properties, there are view factors that should be considered such as materials, mixture proportions, fresh properties of concrete including workability, and compaction. However, the conventional methods that commonly used in the field could cause difficulty in placing, especially for some locations that could not be reached by vibrator.

Recently, the use of Self-Compacting Concrete (SCC) has become an innovative concrete that has been disscused by many scholars. SCC is also called as self-consolidating concrete, self-leveling concrete, super-workable concrete, highly-flowable concrete, and non-vibrating concrete [1]. This kind of concrete has a lot of advantages because it does not require vibration for placing and compaction, cohesive enough to be handled without segregation, easy to flow under its own weight even by the present of reinforcement (flowability and passing ability), and for the application it improves the eficiency that related to the reduction of cost of labor operations. In order to achieve a workable SCC, the mixture must be cohesive with good rheological properties, hence, cement ratio, and moisture content of the constituent ingredients has to be proportioned correctly (High-fluidity).

The use of pozzolan materials like fly ash, blast furnace slag, silica fume and metakaolin has been considered to improve the mechanical properties of SCC [2]. Among those materials, fly ash has been extensively investigated due to its availability as by-product material. In Indonesia, the production of fly ash is around 10 million tons per year with about 50% could be found in Steam Power Plant. As a pozzolan material, fly ash is primarily silicate glass containing silica, alumina, iron and calcium with sizes vary form 1□m - 100□m that can react with cement to increase binding properties. When using fly ash as partial replacement of cement, the addition of fly ash in concrete improves the long term compressive strength, and reduces permeability, bleeding, water demand and heat of hydration of concrete [1]. The spherical particles of fly ash also making the use of water can be lower for mixing and the placement of concrete could be obtained [3].

In SCC mixtures, the use of fly ash has also been studied. A study reported that the replacement of 40% fly ash increased the compressive strength of SCC by reaching the value of 27.2. It also showed a stable mixtures to achieve the workability of fresh concrete based on slump flow test, V-funnel test and J-Ring

test. However, increasing the fly ash content up to 60% by wt. of cement lower the compressive strength at 7, 28 and 56 days [4]. In another study it was also found that the use of fly ash with percentage of 30% by wt. of cement increased the workability due to the small particle sizes and more surface area. This study also found that at the water/cement ratio of 0.23, the SCC mixtures exhibited satisfactory results based on the EFNARC standard [5]. A study from Mushtaq *et al.* [6] was also found the presence of fly ash increased the mechanical properties including compressive, split tensile and flexural strengths off SCC mixtures. The similar study was also reported by Iqbal *et al.* [7]
Based on some previous experimental works, this study aims to investigate the effect of different fineness of fly ash sourced from PLTU II North Sulawesi in Amurang. It is expected that finer particles could improve the workability of SCC mixtures based on slump-flow and L-box tests and also contribute the mechanical properties of concrete containing fly ash.

2. Experimental Methods

2.1 Materials

In this experimental work, Portland Composite Cement (PCC), fly ash (passed a number of 100 sieve) and fine fly ash (passed a number of 200 sieve), water, Viscocrete 3115 N from SIKA with dosage of 1% by wt. of cement, fine aggregate and coarse aggregate are used. The Viscocrete 3115 N is an aqueous solution of modified polycarboxylate copolymers. The dosage that has been selected for this SCC mixtures was taken based on trials mixed that achieved required fresh properties. The physical properties of fine and coarse aggregate is shown in Table 1. Fly ash is Type C sourced from PLTU II Sulawesi Utara, with chemical compositions are listed in Table 2.

Table 1. Physical properties of coarse and fine aggregate

Property	Fine aggregate	Course agregate
Spesific gravity	2.42 gr/cm^3	2.69 gr/cm^3
Water content	8.71%	1.09 %
Water absorption	8.67 %	1.85 %
Maximum size	4.75 mm	19 mm

Table 2. Chemical compositions of PCC and fly ash

No.	Parameter	Compositions (%)	
		PCC	Fly Ash
1	SiO_2	20.92	18.77
2	Al_2O_3	5.49	6.89
3	Fe_2O_3	3.78	21.8
4	CaO	65.21	28.13
5	Na_2O		7.41
6	K_2O		1.38
7	MgO	0.97	4.65
8	SO_3		6.65

2.2 Methodology

Two parts of experimental works were conducted including fresh properties of self-compacting concrete based on slump-flow test and L-box tests referred to EFNARC-standard (Part 1) and the evaluation of compressive strength of concrete at 7, 14 and 28 days and tensile (splitting) strength at 28 days (Part 2).

The classification of slump-flow test and L-box tests based on EFNARC-standard [8] can be seen in Table 3.

Nine concrete cubes for each mixture with size of 150mmx150mmx150mm were cast and tested after water curing for compressive strength analysis while two concrete cylinder specimens for each mixture with size of 150mm/300mm were used for the tensile (splitting) strength test.

The mixture proportions of SCC is shown in Table 4. Normal concrete (denoted as BN), concrete with 15% fly ash (denoted as BFA), concrete with 15% fine fly ash (BFFA) and concrete with 7.5% fly ash and 7.5% fine fly ash (denoted as BFA+BFFA) are considered in this study. The dosage of 15% fly ash by wt. of cement is selected based on the research reported by Wenno *et al* [9]. In his study, it was found that mortar with 15% fly ash sourced from PLTU II North Sulawesi exhibited highest compressive strength at 7 and 28 days compared to other specimens containing 0%, 5%, 10%, 20% and 25%.

Table 3. Classification of SCC fresh properties based on EFNARC-standard [6]

Assessment	Testing	Classes
Filling ability	Slump flow test	Slump flow (mm)
		SF1=550-650
		SF2=660-750
		SF3=760-850
Passing ability	L-box test	h2/h1
		PA1=□0.8 with two bars
		PA2=□0.8 with three bars

Table 4. Mixture proportions of SCC containing fly ash and fine fly ash

Type of mixes	Quantity of materials (kg per m^3)							
	Cement	Fly Ash	Fine Fly Ash	Sand	Coarse Aggregate (5-10 mm)	Coarse Aggregate (10-20 mm)	Viscorete	Water
BN	450	0	0	945	219.8	408.2	4.5	220.5
BFA	382.5	67.5	0	945	219.8	408.2	4.5	220.5
BFFA	382.5	0	67.5	945	219.8	408.2	4.5	220.5
BFA+BFFA	382.5	33.75	33.75	945	219.8	408.2	4.5	220.5

3. Results and discussions

3.1 Flowability and passing ability

The slump-flow and L-box tests provide information of the filling ability (flowability) and passing ability to evaluate the stability and capacity of SCC mixtures without external forces against the friction of the plate. Table 5 shows the results of the fresh properties of SCC mixtures. It can be seen that the mixture containing 15% fine fly ash (BFFA) reached the highest results of flowability and passing ability compared to other mixtures. The results for BFFA mix are 655mm and 0.85 for flowability and passing ability, respectively. It is interesting to be noted that combining fly ash and fine fly ash also produced more workable mixtures when compared to normal and 15% fly ash concretes. This is an indication that fine fly ash has a tendency to improve the fresh properties of SCC mixtures due to more surface area and the round shape fly ash particles that can optimize the ball-bearing effect of fine fly ash. Overall, all SCC mixtures conducted in this experiment fulfilled the allowable ranges in accordance to EFNARC standard.

Table 5. Slump flow and L-box tests results

Type of Mixes	Flowability (mm)	Passing ability (h2/h1)
BN	600	0.8
BFA	622.5	0.81
BFFA	655	0.85
BFA+BFFA	630	0.83

3.2 Compressive strength

Figure 1 shows the compressive strength results at 7, 14, and 28 days. It can be clearly seen that concrete with cement only reached the highest strength at all ages, followed by concrete with combination of fly ash and fine fly ash. The strength results of BN mix are 19 MPa, 26.5 MPa and 36.6 MPa at 7, 14, and 28 days, respectively. Interestingly, there is no so much different of strength was observed on concrete containing 7.5% fly ash and 7.5% fine fly ash with compressive strength values are 18.5 MPa, 23.5 MPa and 34 MPa at 7, 14 and 28 days, respectively. This is suggested that combining different size of fly ash articles in concrete could contributes the packing effect of fly ash resulted in improving the concrete density. On the other hand, it can be also noticed from figure 1 that when the compressive strength of 15% fine fly ash (BFFA) is compared with 15% fly ash (BFA), BFFA shows lower compressive strength which is assumed to the presence of fine particles that can be easily agglomerated during mixing thus prevent the hidration reaction. Considering the concrete properties at early and later ages, the effects of adding fly ash on compressive strength development is more efficient on 28 days in comparison to the strength at 7 days.

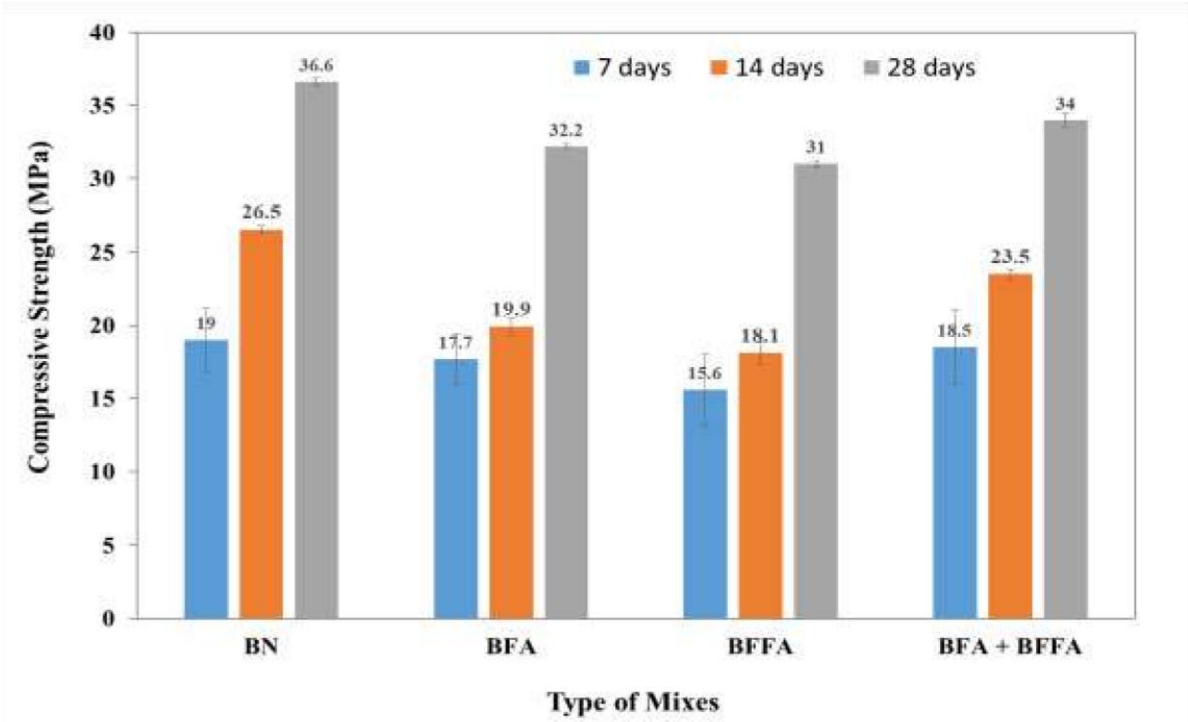

Figure 1. Compressive strength of SCC mixtures at 7, 14 and 28 days

3.3 Tensile strength

The results of tensile (splitting) strength of all types of SCC mixtures at 28 days are shown in figure 2. The trend of tensile strength development of each SCC mixtures is observed similar with the compressive strength. In the figure, it can be clearly seen that the highest tensile strength was found on normal concrete (BN) with the result of 3.14 MPa while the lowest tensile strength was 2.65 MPa which is found in concrete with 15% fine fly ash. The combination of fly ash and fine fly ash again showing better performance on tensile strength when compared to BFA and BFFA concrete mixtures with the tensil strength value of 3.04 at 28 days.

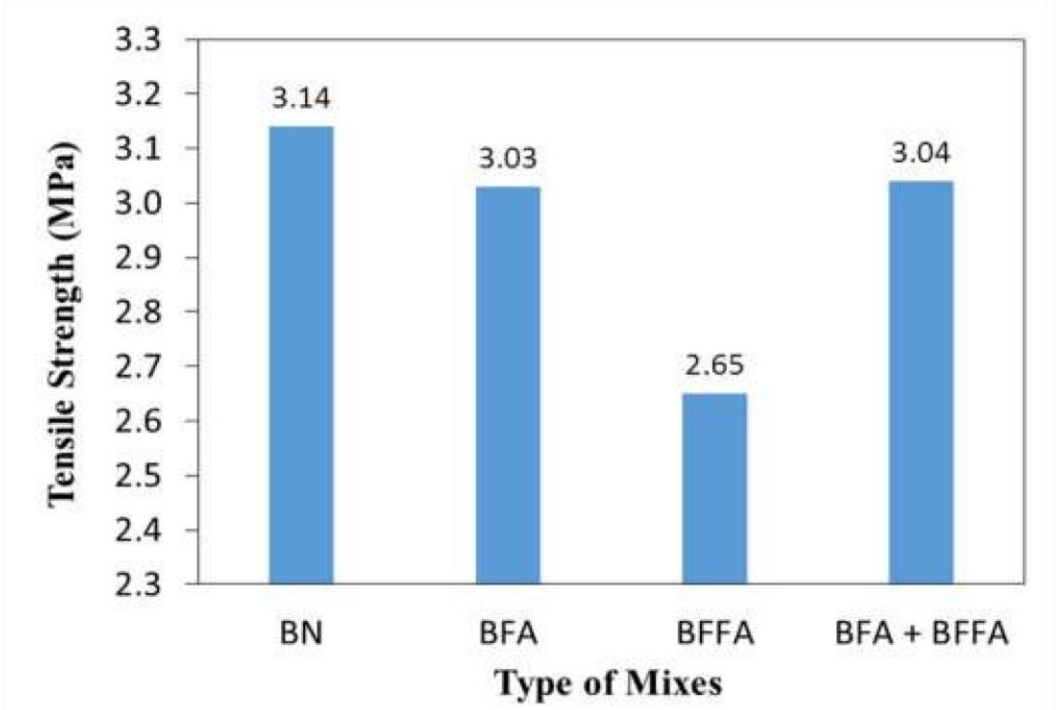

Figure 2. Tensile strength (splitting) results of SCC mixtures at 28 days

4. Conclusions

Based on the experimental results, some conclusions could be drawn as follows:

1. The addition of fine fly ash enhances the flowability and passing ability of SCC based on slumpflow and L-box test results which fullfiled the EFNARC recommendation.
2. Concrete with cement only (BN) reached the highest value of compressive strength at all ages followed by concrete with the combination of fly ash and fine fly ash (BFA+BFFA). However, there is no significant strength development on concrete with 15% fine fly ash (BFFA) compared to concrete with 15% fly ash that can be due to the agglomeration occurred during mixing when using finer particles of fly ash. Considering the properties at early and later ages, the effects of adding fly ash on compressive strength is more efficient on 28 days compared to 7 days due to the chemical composition of fly ash.
3. The highest number of tensile strength is on the mixture of concrete with cement only (BN) while the lowest tensile strength is reached by mixture of concrete with fine fly ash. There are comparable results that can be observed between BFA and BFA+BFFA concretes indicating that combining different size of fly ash particles could lead to better density thus improve the mechanical properties of SCC.

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