MECHANICAL PROPERTIES OF SELF COMPACTING CONCRETE USING FLY ASH

PUBLICATION ARTICLE

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Abstract The purposes of this study were 1) to analyze the effect of fly ash on the mechanical properties of self compacting concrete; and 2) to determine the optimum fly ash content as cement replacement in improving mechanical properties on self compacting concrete at 28 days. This research was conducted in laboratory of Muhammadiyah University Surakarta. Primary and secondary data collection techniques were used in this research experiment. Primary data was collected directly form laboratory experiments. All the data was recorded on a daily basis until the research is completed. The researcher collected the data from the result of self-compacting concrete and compare to other standards to get the level of compressive strength and tensile strength. Self- Compacting Concrete is characterized by filling ability, passing ability and resistance tosegregation. Mechanical properties of self-compacting concrete modified with 0%, 15% and 35% Fly ash as cement replacement were studied. The main goal were to analyses mechanical properties (compressive strength, flexural strength and modulus of elasticity) of self-compacting concrete mix and to determine the optimum amount for Fly Ash replacement for improved mechanical properties. From the study results can be concluded that 1) the Slump Flow test results were increasing as the amount of Fly Ash increased within the allowable ranges of 500-700 mm in accordance to ASTM standard; 2) the compressive strength and modulus of elasticity measurement values decreased as the amount of fly ash increased from 0 to 35% whereas; and 3) the value for improved mechanical property of flexural strength was found at 15% Fly ash content.

Keyword: fly ash, Self-Compacting Concrete

I. INTRODUCTION

Self-Compacting Concrete (SCC), which flows under its own weight and does not require any external vibration for compaction, has revolutionized concrete placement. SCC, was first introduced in the late 1980’s by Japanese researchers, is highly workable concrete that can flow under its own weight through restricted sections without segregation and bleeding. Such concrete should have a relatively low yield value to ensure high flow ability, a moderate viscosity to resist segregation and bleeding, and must maintain its homogeneity during transportation, placing and curing to ensure adequate structural performance and long term durability. The successful development of SCC must ensure a good balance between deformability and stability.

Self-compacting concrete can applied in narrow area because of self-compacting concrete (SCC) does not requires vibration for placing and compaction. It is able to flow under its own weight, completely filling formwork and achieving full compaction, even in the presence of congested reinforcement. The hardened concrete is dense, homogeneous and has the same mechanical properties and durability as traditional vibrated concrete.

As coal is burned in a power plant or industrial boiler, its noncombustible mineral content (ash) is partitioned into bottom ash (or slag), which remains in the furnace, and fly ash, which rises with flue gases. Bottom ash is easy to collect since it is removed during routine cleaning of the boilers. The properties of bottom ash make it a good road base and construction material, and, as such, it can be readily given away or sold. Fly ash, on the other hand, is not so easily disposed of. Most fly ash is captured by pollution control devices before release to the atmosphere (Daniels *et al*., 2002).

The use of fly ash as a material for self-compacting concrete is very beneficial because the use of fly ash reduces permeability, bleeding, water demand and the heat of hydration. It also improves workability, however strength development is slower. For every ton of cement that is a manufactured, approximately one ton of carbon dioxide gas, the main greenhouse gas, is released into the environment. From an environmental perspective, one of the benefits of fly ash is that the replacement of large portions of cement with fly ash serves to reduce CO_2 emissions, thus making concrete an even greener material.

To enhance the properties of fresh and harden concrete, the addition of fly ash can be used as partial replacement of cement. Then, the use of fly ash in concrete is very beneficial because it is not only economical from cost but it also improves the fresh and hardened properties of concrete. Usually, the addition of fly ash is about 10-35% replacement to the cement can helps to maintain the viscosity of concrete resulting to in blockage risk and decreases the superplasticizer requirements.

II. LITERATURE REVIEW

Self-compacting concrete is one of innovative concrete by managing a fluid mixture which can reduce the amount of cementitious materials and total volume of concrete required. In Self-compacting concrete, the fluid mixture can flow under its own weight, completely filling formwork and achieving full compaction in structures even with congested reinforcement. Then, the use of Self-compacting concrete also can increases the speed of construction and reduces noise. Moreover, in terms of Self-compacting concrete, the cost can be reduced by replacing a part of the Portland cement, especially if the mineral admixtures are waste or industrial by-product such as fly ash. Fly ash is a by-product of the combustion of pulverized coal in thermal power plants. Therefore use of fly ash not only provides economical benefits but also reduces heat of hydration Henceforth replacing of Portland cement with fly ash can reduce the production of CO2 (Asha et al, 2013). Self-compacting concrete (SCC) is a fluid mixture, which is suitable for placing in difficult conditions and in structures with congested reinforcement, without vibration (Bartos, 2000).

Fly Ash is a pozzolanic cement replacement that enhances the performance of concrete by increasing compressive strength, improving workability, durability, long term strength, resistance to freeze-thaw damage and reduces permeability, efflorescence shrinkage, thermal cracking, alkali silica reaction and sulfate attack in concrete. Basically using fly ash makes better concrete that is more economical and better for the environment.

Fly ash is one of the most extensively used by-product materials. It is an inorganic, noncombustible, finely divided residue collected or precipitated from the exhaust gases of any industrial furnace. Most of the fly ash particles are solid spheres and some particles, called cenospheres, are hollow. Also present are plerospheres, which are spheres containing smaller spheres inside. The particle sizes in fly ash vary from less than 1 μm to more than 100 μm with the typical particle size measuring less than 20 μm. Their surface area is typically 300 to 500 m^2/kg, although some fly ashes can have surface areas as low as 200 m2/kg and as high as 700 m2/kg. Fly ash is primarily silicate glass containing silica, alumina, iron, and calcium. The relative density or specific gravity of fly ash generally ranges between 1.9 and 2.8 and the color is generally gray or tans (Venkataraju, 2011).

Fly ash improves concrete workability and lower water demand. This is because fly ash pozzoland becomes denser, stronger and generally more durable long terms compared to straight Portland Cement Concrete mixture. Fly ash particles are spherical and have the same size with Portland cement, therefore the need of water is lower for mixing and placing concrete can be obtained.

The reduction in water leads to improved strength. Because some fly ash contains larger or less reactive particles than portland cement, significant hydration can continue for six months or longer, leading to much higher ultimate strength than concrete without fly ash.

Fly ash can reduce the permeability and absorption of concrete. By reducing the permeability of chloride ion ingress, corrosion of embedded steel is greatly decreased. Also, chemical resistance is improved by the reduction of permeability and adsorption. Fly ash is economical because fly ash can substitute Portland cement in concrete mixture and the mixture with fly ash can increase long term strength and durability.

III. RESEARCH METHODOLOGY

Material

Portland cement concrete is the popular material used in civil engineering projects around the world. Some of the reasons for its use are versatility and adaptability, as evidenced by the many types of construction in which it is used, and the minimal maintenance requirements during service.

Generally, aggregates take 70% to 80% of the volume of concrete and have an important influence on its properties. They are granular materials, from natural rock (crushed stone, or natural gravels) and sands. In addition to their use as economical filler, aggregates generally provide concrete with better dimensional stability and wear resistance. Although aggregate strength can play sometimes an important role, for example in high-strength concretes, for most applications the strength of concrete and mix design are essentially independent of the composition of aggregates.

Fly Ash is a pozzolan that reacts with available lime in cement providing more cementitious compounds and is a direct replacement for cement. Fly ash replacement is conducted on a mass basis. Fly ash replacements of 0%, 15%, and 35% will be used.Fly ash that was used for this research is class F fly ash.

Mixed Design

A total of six concrete mixes was tested. The mixes are prepared byvarying the water/binder ratio (w/b) while keeping the paste volume constantand gravel/total aggregate ratioconstant. W/c ratios of 0.47are used. Fly ash replacement is conducted on a mass basis. Fly ash replacements of 0%, 15%, and 35% are tested.

Table 1 Concrete Mix Proportion

Mix type	Coarse aggregate (kg/m^3)	Fine aggregate (kg/m^3)	Water (kg/m^3)	Fly ash (kg/m^3)	Cement (kg/m^3)	Sp (% by weight of cement)	w/c
A (0)	866	884	208	0	442	2% (8.84 kg)	0.47
B (15)	866	884	208	66.3	375.7	2% (7.51 kg)	0.47
C (35)	866	884	208	154.7	287.3	2% (5.75 kg)	0.47

Total volume 2400 Kg/M^3

Analysis

The analysis is conducted after the testing of a specimen by comparing and analyzing the data obtained. The tests that performed are compressive test and modulus of elasticity. The data that resulted from those tests were assessed and investigate about the result. After knowing the data result of each test, then the analysis is conducted and inserts it into the table or graph so it can be seen easily and know the differences of each composition. Finally, Conclusion is drawn.

IV. RESULT AND DISCUSSION

1. Slump Flow Test

Slump Flow was used for providing information on filling ability (flowability) and passing ability (for a stable mix, high flowability tracks with passing ability).The slump flow test used to evaluate the deformation capacity of concrete under its own weight without external forces against the friction of the plate. Slump flow diameter of (500 – 700mm)was measured to the concrete flowing over a level plate after a slump cone is lifted. The test was conducted in accordance to ASTM C 1611.

Table 2 Slump flow test result

Fly Ash (%)	Slump Flow (mm)	Average
0%	571 625	598.0
15%	613 658 560	610.3
35%	687 640 638	655.0

The slump flow test was conducted in according to ASTM C 1611. The test is used to assess the horizontal free flow of SCC in the absence of obstructions. On lifting the slump cone, filled with concrete, the concrete flows. The average diameter of the concrete circle is a measure for the filling ability of the concrete.

The Slump flow was calculated using Eq. 1:

Slump Flow: $$\frac{(d^1 + d^2)}{2}$$

Where:

d^1= the largest diameter of circular spread of the concrete, and

d^2= the circular spread of the concrete at an angle approximately perpendicular to d^1

The observed result for slump test was increased as the fly ash % replacement increased. Kamran and Mishra (2014) reported similar trend on increasing the slump flow as the Fly Ash % replacement increased. Also Vageesh and Reena (2014) and Ali (2014) reported the similar trend on increasing of slump flow as percentage amount replacement of Fly Ash increased.

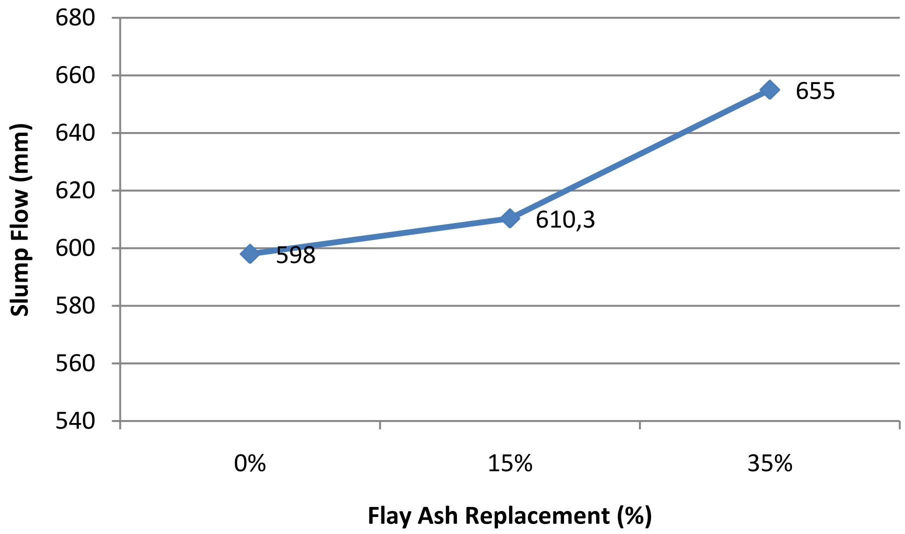

Figure 1 Slump flow result

2. Compressive Strength test

Compressive Strength Test is used to determine the resistance to permanent deformation of normal and modified self-compacting mixtures (RILEM, 2014). Cubes were used to determine compressive strength of SCC. It was conducted by applying a static load to a specimen and then measuring the maximum load. Experimental objects testing is done using UTM (Universal Testing Machine) to obtainthe maximum loadby the unit KN, and then the maximum load press is made to the calculation unit MPa. The compressive strength test is by far the most popular method of shear testing because it is one of the fastest and cheapest methods of measuring shear strength.

Table 3 Compressive strength measured at 28 days

Fly Ash (%)	Compressive Strength (MPa)
0%	30.62
15%	29.37
35%	23.06

Compressive strength measured at 28 days after the concrete been cured for all time shows the decrease in strength as the % Fly Ash increased from 30.62MPa at 0% fly ash for control concrete to 29.37MPa and 23.06MPa at 15% and 35% fly ash replacement respectively as shown in table 3.

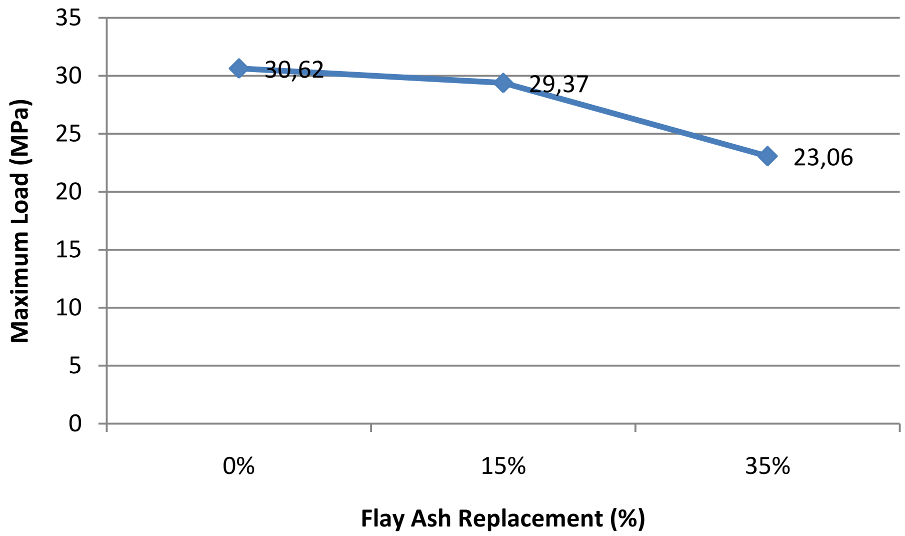

Figure 2 Compressive strength test result of SCC with different percent Fly Ash

The compressive strength test is affected by percentage of fly ash. From the Figure 2 it is clear that there are differences on compressive strength test among all self-compacting concrete mixtures. As shown in figure 2 self-compacting concrete 0% Fly Ash has the highest compressive strength value followed by SCC modified with 15%, 35%. Similarly Ganeshwaran *et al*. (2012) reported that compressive strength decreased with the increase in replacement of cement by fly ash.

Fly ash as filler can fill cavities in the concrete so that the concrete mix to more solid and strong, but the greater the level of fly ash will lower the value of the slump. This happens because the fly ash absorb more water when compared with cement, so that the mixture becomes drier which subsequently affect slump concrete value becomes lower with increasing levels of fly ash used (Pujianto, A., 2010). The greater the levels of fly ash, the water content needed is also increasing, so this affects the value of FAS which resulted in concrete compressive strength decreased while passing through the fly ash content of 15%.

Ankush (2014) investigate the effect of fly ash replacing cement on compressive strength and concluded that an increase fly ash from 10% to 50% decreased compressive strength value from 53.17MPa to 39.25 MPa for 28 days of curing time. Mohamed (2011) reported that higher amount of fly ash had higher values of compressive strength until 30 % of fly ash. However, after the optimum amount of Fly Ash, the increase in Fly Ash decreased the compressive strength of self-compacting concrete. The reason why there is difference in optimum percentage of Fly Ash from the current research is that due to mix design variation in which the amount of cement used in research by Mohamed (2011) is 550 kg/m^3 with W/C of 0.42 whereas in this research it is 440 kg/m^3 with w/c of 0.47.

3. Modulus of Elasticity

The modulus of elasticity (MOE) (Young's modulus) E is a material property, that describes its stiffness. Mechanical deformation puts energy into a material. The energy is stored elastically or dissipated plastically. To this study strength for modulus were determined at 28 day of specimens curing as per ASTM C 469. Three concrete cylinders were prepared with dimensions of 150 mm x 300mm were molded and cured in accordance to standard description.

The concrete were subjected to a slowly increasing longitudinal compressive stress and readings were recorded and MOE were computed and beside it for comparison the modulus was also calculated using the formula $Ec = 4700\sqrt{fc'}$ and all result shown in table 4.

Table 4. Modulus of Elasticity (MOE) at 28 days as ASTM C 469

Fly Ash	Modulus of Elasticity (MPa)	% Decrease	$Ec = 4700\sqrt{fc'}$ (MPa)	% Decrease
0%	26475	0	26008	0
15%	25960	1.945	25471	2.0647
35%	22955	13.295	22568	13.2267

The highest value of modulus of elasticity was found at 0% Fly ash modifier. Similarly Gencel *et al*. (2012) reported that self-compacting concrete with 0% Fly ash modifier had the highest modulus of elasticity value of 36.9 GPa. Similarly, Turk and Karatas (2011) reported that modulus of elasticity of self- compacting concrete decreased with an increase in fly ash content as replacement for cement.

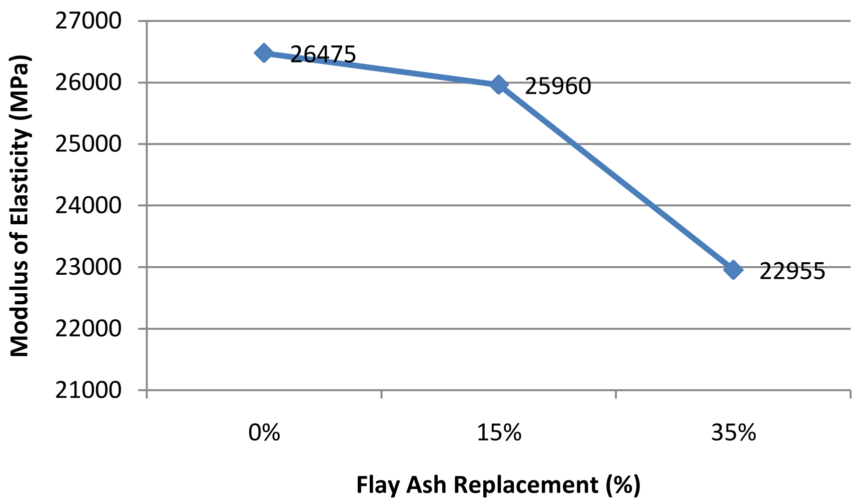

Figure 3 Modulus of elasticity test result of SCC with different percent Fly Ash

4. Flexural Strength

Flexural test measures the force required to bend a beam under three point loading conditions, its data often used to select materials for parts that will support loads against bending load. Flexural modulus is used as an indication of a material's stiffness. This test was done as specified by the ASTM D-790 and ASTM C 78 methods and procedures. The results are presented in table 5. The dimension of the specimens was made in consideration of the size of coarse aggregate 19 mm (20 mm).

Table 5. Flexural Strength (Kg/cm2 or MPa) at 28 days

Fly Ash	Flexural Strength (Kg/cm2)	Flexural Strength (MPa)
0%	53.92	5.3
15%	57.13	5.6
35%	52.77	5.2

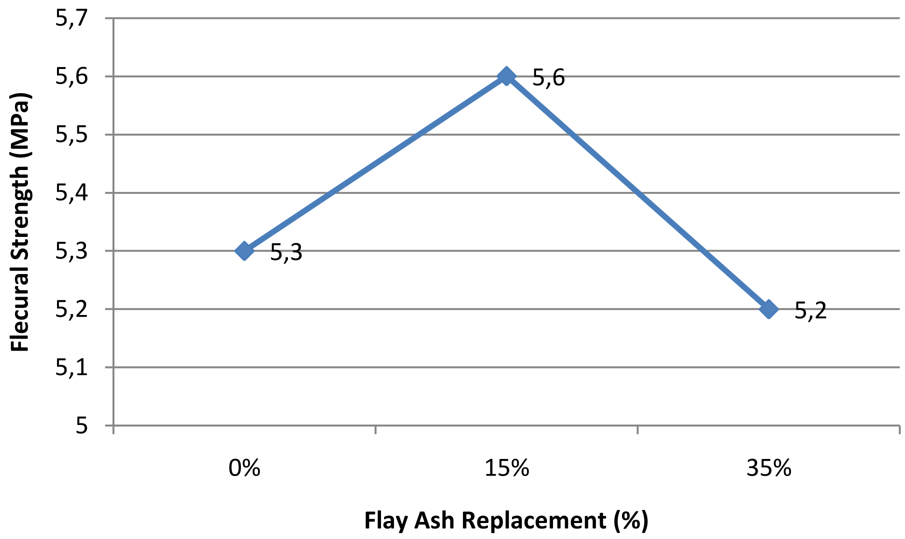

Figure 4. Flexural strength test result of SCC with different percent Fly Ash

The Flexural strength value is affected by percentage of fly ash. From the Figure 4 it is clear that there are differences on Flexural strength test among all self-compacting concrete mixtures. As shown in figure 4.10 self-compacting concrete 15% Fly Ash has the highest Flexural strength value followed by SCC modified with 0%, 35%. In general the flexural strength observed to decrease as the amount of Fly Ash replacement was increased to 35%. The optimum value for flexural strength with Fly Ash replacement recorded at 15% as shown in figure 4.10. Vageesh and Reena (2014) reported the similar trend on flexural strength decrease as the Fly Ash % replacement increased to 30% as compared to 10% and 20% the optimum flexural strength was observed at 10% Fly Ash replacement at 28 days. In addition Gaywala and Raijiwala (2011) reported the same trend and similarly obtained maximum flexural strength at 15% Fly Ash replacement.

Relationship between Flexural strength and Compressive Strength

The Flexural strength test is affected by percentage of fly ash. From the test carried out show that compressive strength and flexural strength for control mix (CM) at 28 days were 30.62MPa and 5.29MPa respectively. On the other side as Fly Ash was added by 15% and 35% decreased compressive strength and increased flexural strength to (29.37MPa and 5.6MPa) and (23.06MPa and 5.2MPa) respectively as shown in figure 5. It is clear that there are differences on Flexural Strength test among all self-compacting concrete mixtures as compared to control mix with 0% Fly Ash. The highest self-compacting concrete with Fly Ash replacement has the highest Flexural Strength value with 15% Fly Ash.

Table 6 Relationship between Flexural strength and Compressive Strength

Fly Ash	Compressive Strength (Mpa)	Flexural Strength (MPa)
0%	30.62	5.3
15%	29.37	5.6
35%	23.06	5.2

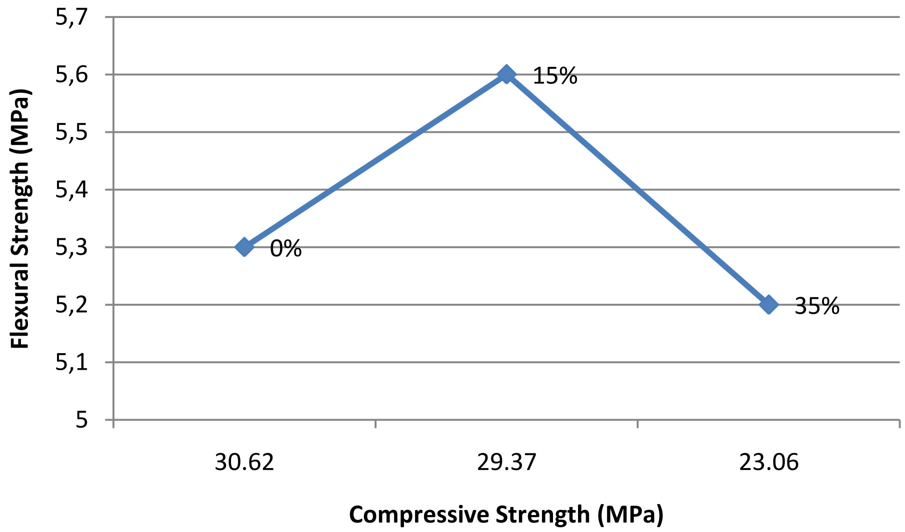

Figure 5 Relationship between compressive strength and Flexural strength at 28 days

It can be seen in figure 5, that compressive strength and flexural strength has inverse relationship at 28 days. As compressive strength decreases, the flexural strength increased at 15% Fly Ash and decreased at 35% Fly Ash but still flexural strength was high as compared to control mix. Gaywala and Raijiwala (2011) and Pai *et al.*, (2014), observed the same trend of relationship between Compressive strength and Flexural strength at 28 days.

Comparison of compressive strength with previous researches

Selected studies together with current study are presented in the table 4.10 to compare the observation made for the similarity and differences in compressive strength in relation to mix proportion and material mix for current study and selected references. For all studies compressive strength with corresponding fly ash modifier were compared at 28 days and the summary of results were as follow; compressive strength for current study was 29.37MPa at 10%, Ganeshwaran *et al*. (2012) was 27.5MPa at 15%, Krishna *et al*. (2013)was 46 MPa at 10%, Fly Ash replacement.

Table 7 Comparison of Compressive strength with relation to properties at 28 days

Author	Cement type	Aggre-gate size	w/c	Mix ratio	Fly Ash %			Maximum CS at 28 days (MPa)	Optimum CS (MPa)
					A	B	C		
This study (2015)	OPC 43	10	0.47	1:2:1.96	0	15	35	30.62 at 0%	29.37 at 15%
Ganeshwaran *et al*. (2012)	OPC 43	20	0.46	1:2:1	0	15	35	28.47 at 0%	27.5 at 15%
Krishna *et al*. (2013)	Birla gold cement (Grade 43)	10	0.4 and 0.45	1:1.85: 1.69	0	10	20 30	53 at 0%	46 at 10%

Comparison between current study and Krishna *et al*. (2013) recorded maximum compressive strength were 29.37MPa at 15% and 46MPa at10% Fly Ash cement replacement measured at 28 days respectively. The observed differences for current study in aggregate ratio (1.2:1.96), water-cement ratio (0.47) and the type of cement (OPC) used as compared to (1:1.85:1.69) and (0.4) and type of cement (Birla gold cement; Grade 43) respectively. RILEM (2014) noted increases in w/c result for more dilution that weaken the ability of the binder (cement) to glue up the aggregates. Also increase the amount of aggregate proportional to cement can result to provide more void for fine aggregate to fill and cement to bind. Birla gold cements (Grade 43) quality, have effect in increasing binding ability for the material as compared to OPC. In addition observed differences from Ganeshwaran *et al*. (2012) can be associated by size of aggregate 20mm and material proportioning 1:2:1 (ratio) as compared to current study 10mm and 1:2:1.96 as shown in table 4.10 respectively.

V. CONCLUSION AND SUGGESTION

1. Conclusion

Mechanical properties of self-compacting concrete modified with 0%, 15% and 35% Fly ash as cement replacement were studied. The main goal were to analyses mechanical properties (compressive strength, flexural strength and modulus of elasticity) of self-compacting concrete mix and to determine the optimum amount for Fly Ash replacement for improved mechanical properties. From the study results the following observation were deducted.

- The Slump Flow test results were increasing as the amount of Fly Ash increased within the allowable ranges of 500-700 mm in accordance to ASTM standard
- The fly ash added to self compacting concrete was influenced the mechanical properties. The 15% and 35% fly ash replacement gradually decreased the compressive strength and modulus of elasticity, while 15% of fly ash replacement was increased the flexural strength and 35% of fly ash replacement was decrease the flexural strength
- The optimum fly ash content as cement replacement to improve mechanical properties (compressive strength, flexural strength, modulus of elasticity) on self compacting concrete at 28 days is 15% fly ash replacement.

2. Suggestion

The result of this research suggests that 15% of Fly Ash replacement as cement can be used for Self compacting concrete. However, to improve the properties of SCC such as compressive strength, flexural strength and modulus of elasticity, the researcher recommends using low w/c ratio since it has an impact on the requirement of super-plasticizer and its properties.

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