Review Article

A Summary on the Use of Fly Ash as a Partial Replacement Material for Cement in Concrete

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Abstract
Cement is one of the most widely used building materials on the planet. Cement manufacturing has also increased carbon emissions to their greatest level in recent years. Alternative or low-emissions binders have become more popular as a partial cement substitute in recent years. Because of its huge yearly output as waste material and low cost, fly ash is now regarded as one of the most accessible choices. Fly ash-based construction materials have a lot of promise as cement substitutes because of their high performance and inexpensive cost. The purpose of this article is to study how fly ash affects the workability, setting time, compressive strength, and tensile strength of concrete. The kinds and characteristics of fly ash were also investigated.

Keywords: Fly Ash, Compressive Strength, Cement, Tensile Strength, Workability.

1. Introduction

Concrete is one of the most utilized "construction materials" due to its durability, accessibility, and strength (Berry, 2009). Globally, over ten billion tons of concrete are produced each year (Babor *et al.*, 2019). Concrete is made up of three basic ingredients: Portland cement (PC), aggregate, and water. Cement is manufactured by combining a variety of basic materials, such as clay and limestone, and heating them to high temperatures to cause chemical reactions. This process consumes huge quantities of energy (about 5% of global consumption each year) and emits massive volumes of carbon dioxide each year (Tafheem *et al.*, 2011). Many researchers have looked at using waste material to replace cement (Valipour *et al.*, 2016). The use of waste material instead of cement in a specified ratio reduces the cost of utilizing cement and allows the production of concrete with fewer environmental consequences and lower costs (Al-Zubaid *et al.*, 2017).

The amount of cement in the concrete mixture can be reduced by substituting alternative pozzolanic materials, which can function as a cement-like binder for some of it (Golewski, 2017). There is a wide range of waste materials that have pozzolanic properties and can be used to replace cement for example fly ash (FA) ground granulated blast furnace slag (GGBFS), silica fume (SF), and rice husk (RHA). These materials are known as supplementary cementitious materials (SCM). Consumption of industrial waste materials instead of cement in concrete manufacturing is an important factor in the conservation of the natural resources, environmental protection by reducing the negative effect of the waste on the environment and solving its disposal problems, energy-saving, and decrease the cost of concrete production (Kotwica *et al.*, 2017). In addition, utilization of waste material would cause a decrease in pollutant emissions from extracting, mining, and handling process (Tafheem *et al.*, 2011). SCM, such as fly ash, may be utilized to make green concrete instead of cement. Green concrete is described as concrete that employs natural and/or recyclable resources in its components to make concrete that is less harmful to the environment, has higher performance, is more durable, and is less expensive (Valipour *et al.*, 2016).

SCM comes in a variety of forms that can be used to partially replace cement in concrete production. The availability, durability, closeness, and cost considerations all factor into the decision to use SCM. One of the most popular waste products utilized as a cement substitute is fly ash (Tafheem *et al.*, 2011). It interacts chemically with water and calcium hydroxide formed during cement hydration, which is why it is only used as a partial substitute for cement. Fly ash concrete is a concrete product made by partially replacing cement with fly ash. The United States of America began developing fly ash as a component of Portland cement concrete in 1930. Fly ash is mostly composed of silica, alumina, and iron. Sodium, potassium, sulfur, magnesium, and Calcium are also found in fly ash (Tafheem *et al.*, 2011).

There are numerous advantages to using fly ash as a cement substitute in concrete, including reduced permeability, improved workability to strengthen the concrete, increased resistance to sulfate attack, reduced alkali-aggregate reaction, reduced crack development, and reduced cement hydration heat (Bhavana *et al.*, 2017). The goal of this study was to study how fly ash as a partial replacement for cement affects the workability, setting time, compressive strength, and tensile strength of concrete.

2. FLY ASH

Steel, iron, and thermal power facilities create fly ash, which is a solid waste product (Panda *et al.*, 2019) as shown in Figure 1. Iron, aluminum, calcium oxide, and silica make up most of the fly ash (Bagheri *et al.*, 2020). Fly ash reacts chemically with calcium hydroxide in concrete to create secondary calcium silicate, making it more durable and stronger than pure cement concrete (George *et al.*, 2012).

The hazardous chemicals present in fly ash are bound in concrete created with fly ash and cement, keeping them from polluting the environment. Fly ash as a cement substitute reduces CO_2 emissions as well as energy and resource use. It increases workability, reduces bleeding, and reduces body temperature (Liew *et al.*, 2020). It acts as a filler in concrete and helps to reduce overall voids (Krishnamoorthi & Kumar, 2013). To densify the matrix and make the concrete stronger and more durable, several construction companies have chosen to partially replace cement with pozzolanic materials such as fly ash (Liew *et al.*, 2020).

2.1 Types of Fly Ash

Due to differences in coal quality, the physical and chemical characteristics of fly ash can vary significantly from one power station to the next. The physical and cementitious characteristics of fly ash are influenced by the composition of the fly ash, the burning temperature, and the rate of cooling (Nath & Sarker, 2011). According to ASTM C 618 (Altwair & Kabir, 2010), fly ash is classified into two types: Class F and Class C. Table 1 (Altwair & Kabir, 2010; Rashad, 2015)shows the primary distinction between Class F and Class C.

Table 1. the main difference between Class F and Class C.

C FA	F FA
1- It is generated from the burning of sub-bituminous coal or lignite	1-It generated from burning bituminous and anthracite coal
2- It has high free lime	2-It has low free lime
3- It contains CaO of more than 10%	3- It contains CaO of less than 10%
4- The sum of three significant oxides (SiO_2, Al_2O_3, and Fe_2O_3) between 50% -70%	4-The sum of three significant oxides (SiO_2, Al_2O_3, and Fe_2O_3) more than 70%
5- It has cementitious properties	5- It has rarely cementitious properties
6- It is generally finer than F FA, because of the higher quantities of alkali sulfate in it.	6- It is generally bigger than C FA, due to the lesser quantities of alkali sulfate in it.

Figure 1. Fly ash powder.

2.2 Physical Properties

Glassy, spherical 'ball bearings', fly ash particles are finer than cement particles (Pitroda1 *et al.*, 2012). Individual fly ash particles range in size from 1 micron to 1 mm (Abushad & Sabri, 2017). Fly ash has a specific gravity (relative density) of 1.9 to 2.8. Blaine fineness (surface area) varies from 300 to 500 m^2/kg (Rashad, 2015). The physical characteristics of fly ash are listed in Table 2.

Table 2. physical properties of fly ash.

properties	(Berndt, 2009)	(Sahmaran *et al.*, 2009)	(Sahmaran *et al.*, 2009)	(Kayali & Ahmed, 2013)	(Memon *et al.*,2010)	(Marthong & Agrawal, 2012)	(Namagga & Atadero, 2009)	(Pati1 *et al.*, 2012)
Specific Gravity (g/cm^3)	**2.35**	**2.27**	**2.08**	**2.13**	**2.54**	**2.13**	**2.71**	-
Blaine fineness (m^2/kg)	341	306	289	310		330		340-360

2.3 Chemical Components

The main chemical components of fly ash are silica (SiO_2), iron (Fe_2O_3), alumina (Al_2O_3), and oxides of calcium (CaO). These chemicals components are responsible for their pozzolanic activity (Mohammadhosseini *et al.*, 2020). Table 3 presents the chemical components of fly ash.

Table 3. chemical components of fly ash.

Chemical Components %	(Nath & Sarker, 2011)	(Dhiyanesh *et al.*, 2013)	(Sathawane *et al.*, 2013)	(Namagga & Atadero, 2009)	(Berndt, 2009)	(Kayali, & Ahmed, 2013)	(Onera *et al.*, 2005)	(Mukherjee *et al.*, 2012)	(Sahmaran *et al.*, 2009)	(Sahmaran *et al.*, 2009)
CaO	**2.13**	**18.67**	**2.0**	**23.45**	**5.54**	**<1**	**2.10**	**0.59**	**10.07**	2.21
SiO_2	**50.50**	**45.98**	**40**	**39.76**	**47.58**	**67.5**	**57.55**	**64.58**	**48.08**	54.13
AI_2O_3	**26.57**	**23.55**	**25**	**14.31**	**26.42**	**23**	**25.16**	**25.89**	**25.87**	25.73
MgO	**1.54**	**1.54**	**3.71**		**0.90**	**<1**	**2.5**	**5.27**	**1.46**	2.12
Fe_2O_3	**13.77**	**4.91**	**6**	**5.56**	**12.19**	**4.5**	**6.5**	**0.26**	**4.54**	6.43
SO_3	**0.41**	**1.47**	**1.74**	**6.19**	**1.08**	**0.1**	**0.19**		**0.55**	0.11
K_2O	**0.77**	**1.8**	**0.80**		**1.9**	**1.5**	**3.65**	**0.041**	**1.22**	4.33
Na_2O_3	**0.45**	**0.24**	**0.96**		**1.5**	**0.5**	**0.66**	**0.027**	**0.73**	0.47
Loss on ignition (LOI)	0.6	2.31	3	1.65	2.20	1	1.66	2.4	1.01	1.34

3. Fresh Properties of Concrete

3.1 Workability

Concrete workability is described as the characteristic of concrete that influences how easy or difficult it is to mix, pour, consolidate, and finish fresh concrete. Slump flow diameter (D) and slump flow time (T50) are two popular measures for determining concrete workability.

The amount of water in the mix affects the workability of fly ash concrete, much as conventional concrete (Wattimena & Hardjito, 2017). Experiments were conducted out by (Sahmaran *et al.,* 2007) and (Sahmaran *et al.,* 2009) As demonstrated in Figure 2, increasing the substitution of PC with FA lowers the (water/ cementitious material (including PC & FA)) (w/cm) ratio. This is due to the lubricating effect of fly ash's spherical particle form and smooth surface, which decreases concrete's water requirement.

As demonstrated in Figures 3 and 4, (Dhiyaneshwaran *et al.*, 2013) and (Sahmaran *et al.*, 2009) conducted tests that indicate that workability (as assessed by D and t50) increases with increasing fly ash substitution up to a certain percentage, then gradually decreases, but remains higher than control concrete. This could be because the small size and spherically shaped particles of fly ash reduce friction between cement paste and aggregates at low replacement levels (Bendapudi & Saha,2011) but as the percentage of fly ash replacement increases, the concrete's workability decreases due to the high surface area of fly ash in the concrete (Xu & Shi, 2018; Mukherjee *et al.*, 2013; Valdez, 2011).

The geometry and surface roughness of the FA (Sahmaran *et al.*, 2007), as well as the rate of PC replacement by FA (Xu & Shi, 2018), have a significant impact on the workability of fly ash concrete. On the other hand, it appears that variations in fly ash chemical composition have less of an impact on workability (Wattimena & Hardjito, 2017).

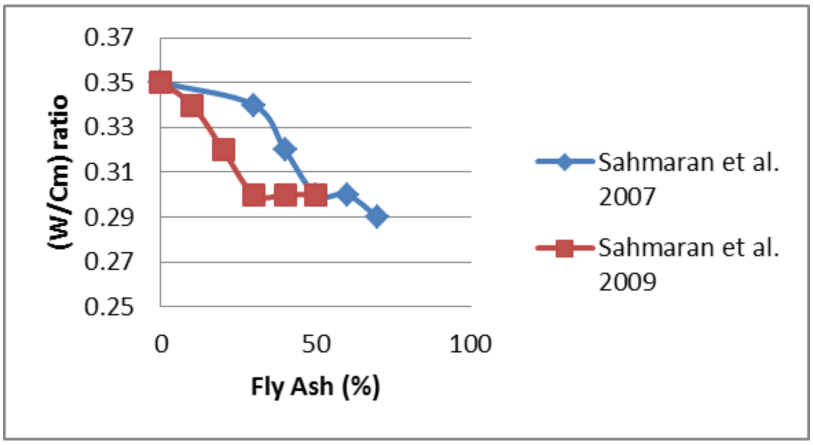

Figure 2. Effect of fly ash content on (w/cm) ratio.

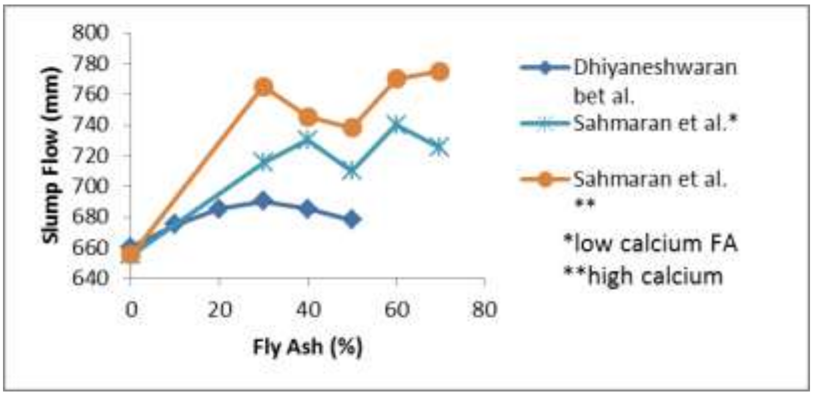

Figure 3. Effect of fly ash content on slump flow.

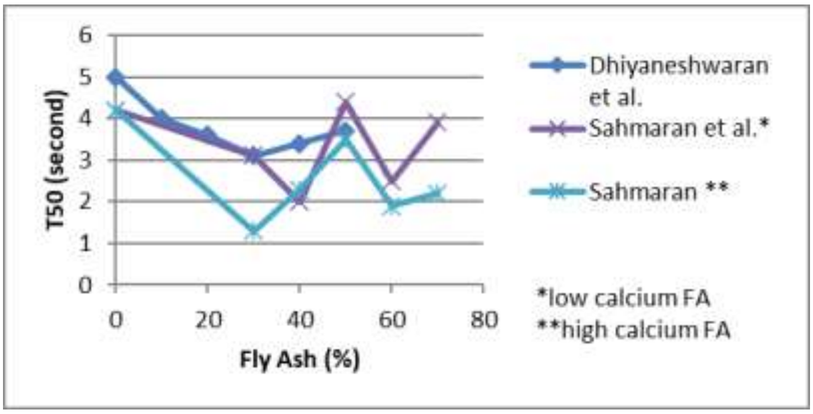

Figure 4. Effect of fly ash content on slump flow time (T50).

3.2 Setting Time

Setting time can be described as the time required for concrete to change from liquid state to solid state.. It is one of the most significant elements in fly ash concretes because it influences the characteristics of the hardened state in addition to the necessity for handling time before putting and compacting (Wattimena & Hardjito, 2017). In comparison to identical concrete prepared without fly ash, fly ash tends to slow down the time it takes for cement to cure (Kesharwan *et al.*, 2017). In general, increasing the number of absorbed calcium ions, which prevents calcium ions concentration build-up in new paste during early hydration, increases the setting time of fly ash concrete. (Sahmaran *et al.*, 2009; Wang, 2004; Kocak & Nas, 2014). The features and quantities of fly ash used in concrete impact the time it takes for fly ash concrete to cure (Bendapudi & Saha,2011; Wang, 2004; Ravina & Mehta, 1986; Siddique, 2008). The use of Class F and Class C fly ashes extends the time it takes for concrete to set. Some kinds of C FA, on the other hand, can induce a fast setting (Wattimena & Hardjito, 2017; Siddique, 2008). According to (Marthong & Agrawal, 2012), when the cement particle size decreases, the setting time reduces. Because there is more surface area available for chemical interaction, the finer the cement, the faster it hydrates. Early hardness and strength development result because of this. The influence of fly ash on concrete setting behavior, according to previous studies, is dependent not only on the composition and quantity of fly ash used but also on the type and amount of cement used, as well as the water content (Siddique, 2008; Sata *et al.*, 2007).

4. Hardened Properties of Fly Ash

4.1 Compressive Strength

The most important test in concrete production is the compressive strength test due to two reasons. Firstly, it is an important test to assess many other properties of concrete. Secondly, it is an easy test to be determined. In fly ash concrete, the compressive strength is affected strongly by the chemical properties of fly ash particularly the content of CaO where high calcium fly ash reacts faster to provide better early age strength (Hemalathaa & Ramaswamy, 2017). Experimental works conducted by (Dhiyaneshwaran *et al.*, 2013) and (Namagga & Atadero, 2009) observed that concrete with fly ash had higher compressive strength than concrete without fly ash after 7 and 28 days. On the other hand, (Sahmaran *et al.,* 2009) discovered that concrete with fly ash had lower compressive strength than concrete without fly ash after 7 and 28 days. This discrepancy might be attributed to the differing ratios of CaO in FA utilized, with the first using fly ash with CaO content of 18.67 percent and 23.45 percent, respectively, and the latter using fly ash with a CaO concentration of 2.21 percent.

At the later age, the compressive strength of fly ash concrete is affected strongly by the content of sio_2 where it reacts with calcium hydroxide to form calcium silicate hydrate, which improves the compressive strength of fly ash concrete (Sata *et al.*, 2007).

From a variety of studies, Table 4 highlights the connection between compressive strength, rate of replacement of PC by FA, time, and (w/cm) ratio. Table 4 demonstrates that the compressive strength of fly ash concrete improves significantly over time when compared to normal concrete. Because of the pozzolanic reaction delay, the pace of strong development in fly ash concrete is sluggish. When calcium hydroxide (CH) is liberated from the cement hydration process, the pozzolanic reaction of fly ash begins. The early strength increase of concrete containing fly ash is hampered as a result of this (Shaikuthali *et al.*, 2019). However, other studies have found a substantial increase in compressive strength at an early age. This might be owing to the use of high Cao content fly ash (C FA), which contributes to strength development at an early age after mixing due to their self-hardening and pozzolanic characteristics. Table 4 further shows that with a high degree of replacement, compressive strength drops considerably. This may be related to the fact that fly ash functions as a pozzolanic ingredient in low-volume fly ash concrete. While only a portion of the fly ash in large volume fly ash concrete participates in the pozzolanic reaction, the other portion remains unreacted even after a lengthy period of curing (Rashad, 2015). According to previous studies, the compressive strength of fly ash concrete is affected by the amount of cement replacement, w/c ratio, and duration, in addition to the physical and chemical characteristics of the fly ash.

Table 4. Compressive strength of fly ash mixed concrete.

		Compressive Strength (MPa) of fly ash concrete at days						Reference
fly ash :cement	**w/cm ratio**	**7**	**28**	**56**	**90**	**180**	**365**	
0:100 10:90 20:80 30:70	0.35	23.18 26.33 25.93 22.08	39.07 43.11 40.59 30.92					(Wankhede & Fulari, 2014)
0:100 20:80 40:60	0.45	29.82 26.68 27.9	46 48.91 46.35	46.66 49.33 47.46				(Swaroop *et al.*, 2013)

0:100 10:90 20:80 30:70 40:60 50:50	According to Normal consistency	26.7 27.4 28.3 30.25 27.75 25.5	40.2 41.9 43.23 45.28 42.00 39.15					(Abushad & Sabri, 2017)
0:100 10:90 20:80 30:70 40:60 0:100 10:90 20:80 30:70 40:60	0.40 0.3	28.77 21.33 16.15 13.04 9.93 34.81 29.33 13.78 13.04 8.59	44. 59 34.67 24.3 22.22 17.33 52.74 38.22 27.56 21.48 20					(Pitroda1 *et al.*, 2012)
0:100 15:85 25:75 35:65 45:55 55:45 65:35 0:100 15:85 25:75 35:65 45:55 55:45 65:35	According to Normal consistency	25 24 18 19 15 10 6 38 37 24 25 28 24 9	46 43 39 37 29 21 14 57 56 54 51 48 41 32	50 47 41 40 32 30 20 61 60 59 55 50 45 37				(Chakraborty & Banerjee , 2016)
0:100 30:70 40:60 50:50 60:40 70:30 0:100 30:70 40:60 50:50 60:40 70:30	0.35 0.32	55.9 40.6 37.4 24.5 21.9 14.9 55.9 38.6 34.5 32 22.8 18.3	62.2 57.3 59.1 40.8 38.1 34.4 62.2 52.4 52.3 47.5 39.9 32.8		69.9 64.9 61.5 47.1 48.8 39.4 69.9 64.9 63.2 59.9 52.1 45	71 66.2 68.3 51 51.7 43 71 69.2 67.2 68.7 62.6 53.7	74.1 70.7 67.3 54.6 56.4 51.8 74.1 75.6 75.6 70 65.8 61.6	(Sahmaran *et al.*, 2009)
0:100 25:75 45:55 0:100 25:75 45:55	0.24 0.19	79.5 74.6 56.3 83.5 74.2 56.4	97.4 105.9 89.4 96.8 102.3 88.5		110.2 124.5 107.2 114.5 123.6 109.2			(Poon *et al.*, 2000)

0:100 10:90 20:80 30:70 40:60 50:50	According to Normal consistency	19.4 21.4 22.6 25.0 26.5 27.2	26.4 28.2 30.8 34.9 38.9 40.0	29.0 31.2 34.0 40.2 44.6 46.3	31.0 34.2 38.0 44.0 49.8 51.4		32.8 36.3 40.5 46.4 52.3 54.8	(Siddique, 2003)

4.2 Splitting Tensile Strength

The size and extent of fractures in concrete are influenced by the tensile strength of the concrete. The most significant element affecting tensile strength is paste quality, which is influenced by fine aggregate characteristics (Mehtaa & Ashishb, 2019). The behavior of concrete's splitting tensile strength is like that of its compressive strength, although it is much lower. Table 5 summarizes the connection between splitting tensile strength, rate of replacement of PC by FA, time, and (w/cm) ratio for many investigations. As shown in table 5, the splitting tensile strength of fly ash concretes appeared to be greater than that of control concrete since the grain and pore refinement of concrete resulted from the fineness of particles and the pozzolanic reaction of the ashes. However, it has been shown that tensile strength rises with increasing fly ash content up to a specific percentage and declines at high levels of replacement in some situations. This might be because the fly ash enhances the interfacial connection between the aggregate and the paste in a low-volume fly ash concrete. The fly ash, on the other hand, reduces the interfacial connection between the aggregate and the paste in high-volume fly ash concrete (Dhiyaneshwaran, 2013; Magureanu and Negrutiu, 2009). Table 5 further shows that the splitting tensile strength of all mixtures continued to grow with age (Siddique, 2003).

Table 5. Splitting Tensile Strength of fly ash mixed concrete.

		Splitting Tensile Strength (MPa) of fly ash concrete at days					Reference
fly ash :cement	**w/cm ratio**	**7**	**28**	**56**	**90**	**365**	
0:100 10:90 15:85 20:80 30:70 40:60	According to Normal consistency		1.72 1.58 1.58 0.89 1.21 0.89				(Barbuta *et al.*, 2016)
0:100 10:90 20:80 30:70 40:60	0.4			3.44 3.52 3.21 2.55 2.41			(Pitroda1 *et al.*, 2012)
0:100 10:90 20:80 30:70 40:60	0.3			3.96 4.1 2.78 2.69 2.04			
0:100 10:90 20:80 30:70 40:60 50:50	According to Normal consistency	1.08 1.23 1.34 1.47 1.36 1.28	1.74 1.88 2.01 2.06 1.96 1.84				(Dhiyaneshwaran *et al.*, 2013)
0:100 10:90 20:80 30:70 40:60 50:50	0.49	2.5 2.6 2.6 2.7 2.8 2.7	3.0 3.1 3.2 3.4 3.5 3.5	3.2 3.3 3.4 3.7 3.9 4.0	3.3 3.5 3.6 4.0 4.2 4.3	3.4 3.6 3.8 4.2 4.4 4.4	(Poon *et al.*, 2000)

5. Conclusions

Based on the discussion above, the following conclusions were drawn:

1- The use of fly ash in concrete reduces water content up to a certain limit, if you keep increasing the FA percentage in concrete water demand increases to maintain the required workability.

2- The workability of fly ash concrete is affected by the geometry and surface roughness of the FA.

3- The chemical composition of the fly ash has a lesser impact on workability, but it has a greater impact on setting time.

4- The optimal content of fly ash in concrete depends on its physical and chemical properties

5- The value of compressive strength and tensile strength depends on the level of cement replacement, type of FA, and age.

6- The behavior of concrete's splitting tensile strength is like that of its compressive strength.

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