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Performance of Self Compacted Concrete using High Volume of Activated Fly Ash - A Literature Review

[1]Ashish Sharma, [2]Dr. J N Vyas

[1]PG Student, [2]Professor
[1,2]Department of Civil Engineering
[1,2]Mahakal Institute of Technology and Management, Ujjain, India

Abstract—

The self-compacting concrete is most important development in this concrete Era, This world needs sustainable development in the every aspect of resources utilization. The goal of this research is to replacement in concrete with activated fly ash. Activated fly ash enhances the strength and durability of concrete at an early age, as well as its corrosion resistance. The fly ash is activated using a variety of processes, including mechanical (physical), thermal, and chemical activation. Chemical activation of fly ash by alkaline activators (i.e. alkaline solutions of high alkaline concentration chemicals like gypsum, sodium silicate and calcium oxide, KOH, etc.) improves the effectiveness of fly ash by dissolving the glassy layer of fly ash particles in cement concrete, increasing corrosion resistance. Chemical treatment of fly ash using chemical activators is used in this study to increase its quality. The previous researches show very satisfactory that the fly ash can be used to improve the properties of self compaction concrete. In this work, literatures were carried out for the effective replacement of cement activated fly ash at different proportions. The aim was to investigate the characteristics of concrete with the addition of activated fly ash and comparing it with the control mix, thereby determining the advantages and disadvantages of doing so.

Keywords*: Conventional Concrete, Activated Fly Ash, Compressive Strength, Flexural Strength, Tensile Strength, Workability,.*

1. Introduction –

Concrete is the most widely used man made construction material in the world. Seeking aggregates for concrete and to dispose of the waste from various commodities is the present concern. Today sustainability has got top priority in construction industry. In this study the recycled plastics were used to prepare the fine aggregates thereby providing a sustainable option to deal with the plastic waste. There are many recycling plants across the world, but as plastics are recycled they lose their strength with the number of recycling. So these plastics will end up as earth fill. In this circumstance instead of recycling it repeatedly, if it is utilized to prepare aggregates for concrete, it will be a boon to the construction industry. The productive use of waste material represents a means of alleviating some of the problems of solid waste management .The recycle of wastes is important from different points of view. It helps to save and sustain natural resources that are not replenished, it decreases the pollution of the. Wastes and industrial by-products should be considered as potentially valuable resources merely awaiting appropriate treatment and application.

In many infrastructure projects, concrete is the most often utilized building material. In all fields of contemporary construction, concrete has risen to the rank of key building material. When strength, durability, permeability, fire resistance, and absorption resistance are necessary, concrete is the ideal material to use. Compressive strength is used as a measure to evaluate the entire quality of concrete, and it is widely accepted that when compressive strength improves, all other qualities increase as well. As a result, compressive strengths are usually the focus of strength tests. Although concrete mixes are proportioned to achieve the necessary compressive strength at the stipulated age, flexural strengths are often important in the production of concrete. Because of the considerations of cost savings, energy savings, environmental protection, and resource conservation, the usage of supplemental cementitious materials (SCM) for cement substitution has drastically expanded along with the expansion of the concrete industry. On the one hand, large scale cement manufacturing adds to environmental concerns while depleting natural resources on the other. Fly ash is one of the most regularly utilized mineral admixtures since it is widely accessible in many poor nations. According to the Indian government's estimates, power plants would use 1800 million tons of coal by 2031-2032, resulting in 600 million tons of fly ash. The use of fly ash as a concrete additive not only improves the technical features of concrete but also helps to reduce pollution in the environment. The fly ash may be utilized in two ways: one is to integrand a particular proportion of fly ash with cement clinker at the plant to generate Portland pozzolana cement (PPC), and the other is to use the fly ash as an additive when building concrete on the job site. The latter technique allows the user more latitude and flexibility when it comes to the proportion of fly ash to be added.

Definition of Self Compacting Concrete - The British Standard (BS EN 206-9, 2010) defines "SCC is the concrete that is able to flow and compact under its own weight; fill the formwork with its reinforcement, ducts, boxouts etc, whilst maintaining homogeneity". Other researchers (Ozawa et al. 1989; Bartos and Marrs, 1999; Khayat, 1999) have defined SCC in almost the same terms as a highly flowable.

FLY ASH - Use of Fly Ash has become essential for civil engineering because of its economic and environmental benefits (Ravina and Mehta, 1986; Matkovi´c, 1990). The amount of cement that FA can replace is restricted by the amount of free lime in the ash. Aside from its chemical composition, the reactivity of FA is determined by its phase composition, the amount of glassy phase present, the burning temperature of coal or lignite, the specific surface area (SSA), etc. (Matkovi´c, 1990). FA is a pozzolanic material (Tillman et al., 2012). The term pozzolanic refers to materials that, when exposed to lime and water, will form insoluble cementitious compounds, although they have little or no cementing action when they exist alone (Montgomery et al., 1981).

FA, or pulverised fuel ash, is a byproduct of coal-fired power plants and is used as a mineral additive in cement and concrete. Fig. 1 shows a typical layout of a coal-burning generating station. Pulverized coal is blown into the burning zone of the furnace, where its combustible constituents, mainly carbon, hydrogen, and oxygen, ignite at around 1500 ◦C (2700◦F). Quartz, calcite, gypsum, pyrite, feldspar, clay minerals, and other non-combustible minerals are melted at this temperature and form tiny liquid droplets. The droplets carried by the flue gases from the burning zone are cooled rapidly to form small spherical glassy particles. Mechanical and electrical precipitators or baghouses collect solid particles from flue gases. FA refers to the ash particles that “fly” away from the furnace with the flue gases (Thomas, 2013). The features of FA are influenced by various factors, including the type of coal used, the burning conditions, the collection mechanism, etc. (McCarthy and Dyer, 2019). The use of FA as a pozzolanic ingredient and its reaction potentials were first recognized in early 1914; however, a substantial study on the use of FA in concrete was first published in 1937 in the United States (McCarthy and Dyer, 2019; Halstead). In the earlier studies in the 1980 s, it was reported that replacing concrete with

FA can significantly improve the mechanical and durability properties of concrete (Montgomery et al., 1981) as FA can improve the microstructure of the paste (Filho et al., 2013). Depending on the application, FA properties, specification limits, geographic location, and climate, FA has traditionally been incorporated in concrete at levels ranging from 15 to 25 % by mass of the cementitious material component (Thomas, 2007). It was reported that, in some rare cases, concrete had been successfully placed incorporating up to 80 % FA (Marceau et al., 2002). The FAs used in concrete are of two types class F and class C according to ASTM. The class F FA is a byproduct of bituminous coal combustion. The iron, silica, and alumina content of class F FA is high, but the calcium content is low. It’s a glassy substance that requires either cement or lime to activate. FA from sub-bituminous coal and lignite combustion is classified as class C. It contains more calcium than class F FA. Concrete containing class C FA develops strength much more quickly than concrete containing class F FA (McCarthy and Dyer, 2019; Marceau et al., 2002). The use of FA in concrete is cost-effective, but it also changes the concrete properties in its fresh and hardened states, improving workability, strength, and drying shrinkage. Furthermore, the use of FA in concrete solves the storage and disposal problem of FA, an industrial byproduct (Atis ̧, 2003).

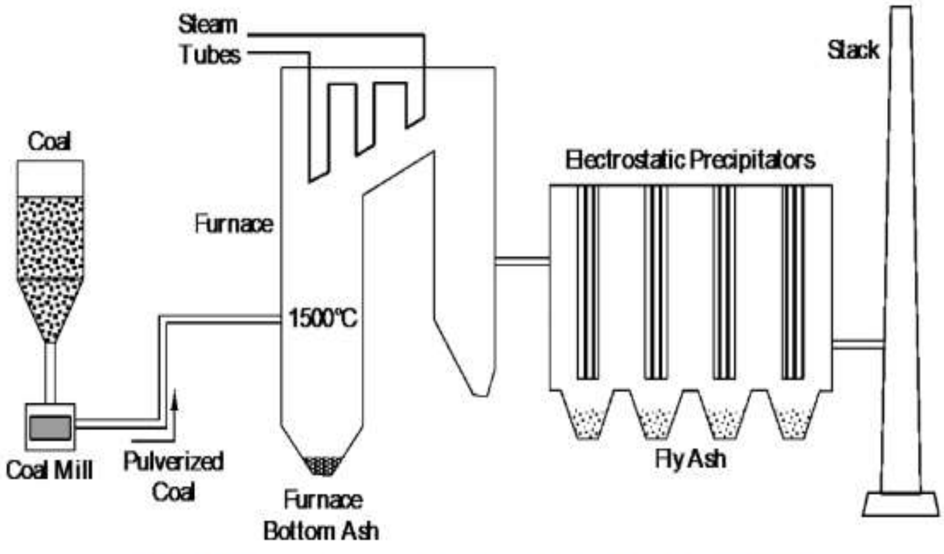

Fig. 1. A schematic diagram of a coal-fired electrical generating station (Thomas, 2013).

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2. OBJECTIVES OF THE STUDY

The main objective of this research is to compare conventional concrete and concrete with activated fly ash in terms of its workability and strength. The use of various materials like phosphor-gypsum, fly ash, GGBS, quarry dust, broken bricks etc in concrete helps in minimizing the resources consumption used to develop the conventional concrete and provide benefits like improved strength and workability of concrete with useful disposal of by-products. This type of concrete will also used to control the energy consumption and will able to minimize the hazards caused to the environment.

3. Literature Review –

There were various studies been conducted on the use of such recyclable materials in concrete which gives adequate strength and its durability. The studies also suggests about the difficulties arise for the use of such by-products in the proportion of concrete. Few of the data from previous studies have been discussed here along with the methodology adopted and conclusions. Many research investigations have been carried out regarding the use of such by-products to minimize the amount of energy consumed and also to reduce the damage to the surrounding environment.

Siddique (Siddique, 2004) Siddique, R., 2004. Properties of concrete incorporating high volumes of class F fly ash and san fibers. Cem. Concr. Res. 34 (1), 37–42. https://doi.org/10.1016/S0008- 8846(03)00192-3 reported that slump heights in HVFAC increased by 20, 25, and 35 mm, respectively, as compared with the control sample, at replacement levels of 45, 50, and 55 % FA.

According to **Khatib** (Khatib, 2008 Khatib, J.M., 2008. Performance of self-compacting concrete containing fly ash. Constr. Build. Mater. 22 (9), 1963–1971. https://doi.org/10.1016/j. conbuildmat.2007.07.011.) a high percentage of FA can be utilized to generate SCC with sufficient strength since the study found that using up to 60 % FA as a cement substitute resulted in the strength of up to 40 N/mm2.

Nath et al. (Nath and Sarker, 2011) Nath, P., Sarker, P., 2011. "Effect of fly ash on the durability properties of high strength concrete". Procedia Eng. 14, 1149–1156. https://doi.org/10.1016/j. proeng.2011.07.144 - demonstrated that as the concentration of FA increased, the slump increased. In comparison to the reference concrete, an increase in slump height of 16.67 and 6.67 % was recorded with 30 % and 40 % FA substitution, respectively, at a 0.29 w/ b ratio. As the FA proportion increased from 20 to 30 %, the slump height of the concrete decreased by around 8 % to 20 %.

Tangchirapat et al., 2013 Tangchirapat, W., Rattanashotinunt, C., Buranasing, R., Jaturapitakkul, C., 2013. Influence of Fly Ash on Slump Loss and Strength of Concrete Fully Incorporating Recycled Concrete Aggregates. J. Mater. Civ. Eng. 25 (2), 243–251. https://doi.org/ 10.1061/(asce)mt.1943-5533.0000585 The workability of concrete with recycled coarse aggregate (RCA) increased as the percentage FA replacement level increased. Slump height increased by 0, 14.2, and 21.42 % when FA was replaced with OPC by 20, 35, and 50 %, respectively, compared to recycled aggregate concrete (RAC) without FA.

Another experiment (**Turk et al., 2013**) Turk, K., Karatas, M., Gonen, T., 2013. Effect of Fly Ash and Silica Fume on compressive strength, sorptivity and carbonation of SCC. KSCE J. Civ. Eng. 17 (1), 202–209. https://doi.org/10.1007/s12205-013-1680-3.on SCC demonstrated a similar early strength drop as FA dosage increased; however, after 130 days of curing, adding FA up to 40 % enhanced SCC strength but remained lower than the control sample without FA.

According to **Mardani-Aghabaglou and Ramyar** (Mardani-Aghabaglou and Ramyar, 2013) Mardani-Aghabaglou, A., Andiç-Çakir, Ȯ., Ramyar, K., 2013. Freeze-thaw resistance and transport properties of high-volume fly ash roller compacted concrete designed by maximum density method. Cem. Concr. Compos. 37 (1), 259–266. https://doi.org/ 10.1016/j.cemconcomp.2013.01.009, when the cement was partially replaced with FA, the strength decreased as the FA content increased, which was attributed partly to the higher w/b ratio partly to FA contributing less strength than cement. However, when the aggregate was partially replaced with FA, the strength of the concrete increased faster and more than the control concrete owing to the improved compactibility.

A similar observation was reported by **Liu and Presuel- Moreno** (Liu and Presuel-Moreno, 2014) Liu, Y., Presuel-Moreno, F. "Effect of Elevated Temperature Curing on Compressive Strength and Electrical Resistivity of Concrete with Fly Ash and Ground-Granulated Blast-Furnace Slag," ACI Struct. J., vol. 111, no. 5, pp. 531–542, 2014, 10.14359/ 51686913- In both reference concrete and FA concrete, the CS increased with age due to the continued hydration of OPC and the increased pozzolanic reactivity of FA, respectively. A partial replacement of 50 % OPC with FA reduced the concrete CS by 57.34, 41.61, 37.50, 29.42, 28.32, and 35.52 %, respectively, at 3, 14, 28, 56, and 91 days and 1 year. According to Liu and Presuel-Moreno, when limestone and granite were used as coarse aggregates, the 28-day CS decreased by 38.72 and 49.68 %, respectively, as the FA concentration increased from 20 to 50 %. However, the long term strength, at more than 600 days, the reduction was only 7.12 and 10.62 %, respectively. FA with limestone offered a higher strength compared to FA and granite combination.

According to **Antoni et al.** (Antoni and Hardjito, 2015) Antoni, L.C., Hardjito, D., 2015. The impact of using fly ash, silica fume and calcium carbonate on the workability and compressive strength of mortar. Procedia Eng. 125, 773–779. https://doi.org/10.1016/j.proeng.2015.11.132a flow table test conducted with ASTM standards indicated that using up to 30 % FA as a replacement for cement increased the workability of fresh mortar. The presence of FA also reduced the superplasticizer (SP) demand.

Shaikh et al. (Shaikh and Supit, 2015) Shaikh, F.U.A., Supit, S.W.M., 2015. Compressive strength and durability properties of high volume fly ash (HVFA) concretes containing ultrafine fly ash (UFFA). Constr.Build. Mater. 82, 192–205. https://doi.org/10.1016/j.conbuildmat.2015.02.068 examined the durability and CS properties of HVFAC containing ultrafine FA (UFFA). Concrete with 8 % UFFA had the highest CS at all ages. With the inclusion of 8 % UFFA, the early age CS of HVFA cement was improved. The most substantial improvement of almost 200 % in CS was observed in HVFAC, containing 52 % FA and 8 % UFFA, after 3 days. Additionally, the inclusion of 8 % UFFA increased the long-term (90 days) CS of ordinary concrete and HVFAC containing 32 % FA by approximately 55 and 10 %, respectively. The small particles of UFFA and high amorphous content accelerated the pozzolanic reaction, filling the pores in the concrete and enhancing its CS. Small FA particles with a high surface area and amorphous silica content imparted the pozzolanic reaction and increased strength over a longer time than Portland cement (PC)

The formation of the extra CSH gel resulted in increased Compressive strength, as **Han-Seung et al.** (Han-Seung and Wang, 2016 Han-Seung, L., Wang, X.Y., 2016. Evaluation of compressive strength development and carbonation depth of high volume slag-blended concrete. Constr. Build. Mater. 124, 45–54. https://doi.org/10.1016/j.conbuildmat.2016.07.070) reported.

Kurda et al. (Kurda et al., 2017) Kurda, R., de Brito, J., Silvestre, J.D., 2017. Influence of recycled aggregates and high contents of fly ash on concrete fresh properties. Cem. Concr. Compos. 84 (2017), 198–213. https://doi.org/10.1016/j.cemconcomp.2017.09.009observed that when 30 % or 60 % FA was used in place of cement in RAC, the amount of water required to achieve the desired slump value of the mix with or without SP decreased.

Another investigation (**Revathi and Nikesh, 2018**) Revathi, P., Nikesh, P., 2018. Effect of fly-ash on corrosion resistance characteristics of rebar embedded in recycled aggregate concrete. J. Inst. Eng. Ser. A 99 (3), 473–483. https://doi.org/10.1007/s40030-018-0295-6 found that adding 10, 20, and 30 % FA as cement replacement increased slump height by 30, 60, and 80 mm, respectively, compared with control RAC.

According to a comparative study **(Nguyen et al., 2018)** Nguyen, T.B.T., Saengsoy, W., Tangtermsirikul, S., 2018. Effect of initial moisture of wet fly ash on the workability and compressive strength of mortar and concrete. Constr. Build. Mater. 183, 408–416. https://doi.org/10.1016/j.conbuildmat.2018.06.192. of mortar and concrete with wet and dry FA of up to 30 %, the wet FA was more workable than a cement-only mix. At the 30 and 50 % FA replacement levels, the slump height increased by 33.33 and 83.33 % at 0.5 w/b and 28 and 85.7 % at 0.4 w/b respectively, attributed to the reduced viscosity associated with higher FA concentration, which resulted in enhanced flow ability and slump.

According to **Saha** (Saha, 2018) Saha, A.K., 2018. Effect of class F fly ash on the durability properties of concrete. Sustain. Environ. Res. 28 (1), 25–31. https://doi.org/10.1016/j.serj.2017.09.001 the CS of class F FA concrete reduced after 28 days of curing, and the strength decreased sharply with increasing FA concentration. On the other hand, due to pozzolanic re-actions, the CS of 30 and 40 % FA concrete increased gradually up to 180 days but remained lower than that of reference concrete until 360 days. Increasing the volume of class F FA resulted in poor CS due to a lack of lime. Concrete containing FA hydrates slowly, leading to low CS in the early ages. The CS of the 10 % FA samples increased rapidly from 7 to 56 days after curing, after which the strength gain became steady. CS of concrete samples containing 20 % FA increased rapidly from 7 to 90 days of curing, while the strength of concrete containing 30 % and 40 % FA increased rapidly from 7 to 180 days of curing, after which a steady increase in strength was observed. After a year of curing, the FA samples had CSs of 88, 82, 87, and 83 % of the control concrete. The use of 30 % class F FA in concrete with Ferronickel slag (FNS) as a sand replacement caused a reduction in CS. The reduction of CS of FA concrete mix is due to low calcium content (0.6 %).

Jena and Panda (Jena and Panda, 2018) Jena, T., Panda, K.C. “Mechanical and durability properties of marine concrete using fly ash and silpozz,” Adv. Concr. Constr., vol. 6, no. 1, pp. 47–68, 2018, 10.12989/ acc.2018.6.1.047 investigated the combined effect of FA and silpozz (a byproduct of rice husk) in marine concrete and noticed that by replacing OPC with 10 % FA plus 20 % silpozz, the CS of concrete increased compared to the control sample. In normal water cured (NWC) ternary samples, the rates of CS increase were 19, 9.5, 7, 6, and 6 %, while in seawater cured (SWC) samples, the rates of increase were 9.5, 20.7, 10.6, 8.3, and 7.8 % after 7, 28, 90, 180, and 365 days, respectively. Among all the samples, including the control specimen, concrete with 30 % FA and 20 % silpozz exhibited relatively low strength at all ages. The study suggested that developing a large CSH gel and dense microstructure in concrete increased its CS.

Sadrmomtazi et al. (Sadrmomtazi et al., 2018) Sadrmomtazi, A., Tahmouresi, B., Khoshkbijari, R.K., 2018. Effect of fly ash and silica fume on transition zone, pore structure and permeability of concrete. Mag. Concr. Res. 70 (10), 519–532. https://doi.org/10.1680/jmacr.16.00537.investigated the effect of FA in concrete with SF and found a decrease in 28 days CS as FA content increased; however, the CS of concrete with 10 % FA was the same as that of reference concrete at 7 days and increased up to 14 % in the long term. Additionally, it was observed that introducing 5 % SF into FA increased CS even at early ages and that combining 20 % FA with 5 % SF resulted in a 20 % increase in 90 days strength over the control sample. This is because the addition of finer SF particles enhanced the pozzolanic reaction with calcium hydroxide (CH).

According to **Praveen Kumar and Ravi Prasad** (Praveen Kumar and Ravi Prasad, 2019) Praveen Kumar, V.V., Ravi Prasad, D. “Influence of Supplementary Cementitious Materials on Strength and Durability Characteristics of Concrete,” Adv. Concr. Constr., vol. 7, no. 2, pp. 75–85, 2019, 10.12989/acc.2019.7.2.075, when OPC was replaced with FA (5, 10, 15, 20, and 25 %), silica fume, SF (4, 6, 8, and 10 %), and lime sludge (LS of 5, 10, 15, and 20 %), the CS of the ternary admixed concrete increased with an increase of FA dosage up to 15 %, then began to decline as the FA dosage increased, but the strength remained higher than the control sample at all w/b ratios of 0.59, 0.39, and 0.32. The CS of ternary admixed concrete of 30, 50, and 70 MPa increased by 42.5, 32.48, and 22.79 %, respectively, when 15 % FA, 10 % LS, and 8 % SF were used in place of OPC. FA is a pozzolanic substance that forms a CSH gel when it reacts with calcium hydroxide (CH) produced by cement hydration. The above study reported that the additional CSH gel formation was due to high silica concentration in FA and SF and high calcium content in cement and LS.

In a study of Saudi-FA-based concrete with a high proportion of class C FA by **Mugahed Amran et al.** (Mugahed Amran et al., 2020) Mugahed Amran, Y.H., Soto, M.G., Alyousef, R., El-Zeadani, M., Alabduljabbar, H., Aune, V., 2020. Performance investigation of high-proportion Saudi-fly-ash-based concrete. Results Eng. 6 (February), 100118 https://doi.org/10.1016/j.rineng.2020.100118, the CS decreased with a rise in FA percentage from 10 % to 50 % at all ages up to 365 days.

However, according to the findings o **Fantu et al.** (Fantu et al., 2021) Fantu, T., Alemayehu, G., Kebede, G., Abebe, Y., Selvaraj, S.K., Paramasivam, V., 2021. Experimental investigation of compressive strength for fly ash on high strength concrete C-55 grade. Mater. Today Proc. 46, 7507–7517. https://doi.org/10.1016/j. matpr.2021.01.213. replacing cement with FA by up to 10 % increased the slump values. In contrast, substituting more than 10 % of the cement with FA reduced the workability of fresh concrete. Conversely, due to the dispersion of cement particles by SP, slump values of concrete with SP increased while partial substitution of cement with FA was up to 20 %.

3. Conclusion –

It was important to note that the quantity of by-product played a vital role to the properties of concrete. From all the previous studies, following points have been concluded:

- There is significant potential in activated fly ash to produce such type of concrete.
- To use fly ash as a replacement of cement in concrete.
- To conduct experimental analysis for the strength of different grades of concrete with activated fly ash.
- To compare the economic feasibility of conventional concrete and such type of concrete made with fly ash.
- To check the suitability of such materials in higher grade of concrete.
- To conduct durability tests on high-performance concrete.

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