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Term Engineering Paper: -

Fresh and Hardened Properties of Concretes with Fly Ash

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Contents

1. Introduction

Fly ashes are unused products of coal burning in electric and thermal power plants. Fly ashes are taken electrostatically in electro filters or mechanically by cyclones and then they are placed directly into ponds or landfills, where they can become harmful to the environment [1]. The composition of fly ash depends on the sort of coal subjected to burning and the combustion situations. The major components of ashes are minerals as calcite, kaolinite, quartz, mulliteand pyrite [2]. High contents of silicates and alumina–silicates suggest their weakness to change into zeolite-like crystalline materials such as a result of chemical treatment.

Fly ash has been widely used in the concrete industry. Its chemical and mineralogical compositions vary greatly depending on many factors as the type of coal and burning situations. Several countries' standards cannot be directly practical because of differences in properties and characteristics of fly ashes in different countries [3].

In addition to the fly ash which composes the principal part of the waste, portion of the waste ashes clinkers together to form large particles that drop to the bottom of the furnace. These are collected as furnace bottom ash. Several furnaces produce a molten residue which is known as boiler slag. This is tapped off from the furnace and is usually granulated with water. These materials can be employed as aggregates for some uses, generally not in concrete .

Figure 1: Fly ash and bottom ash material.

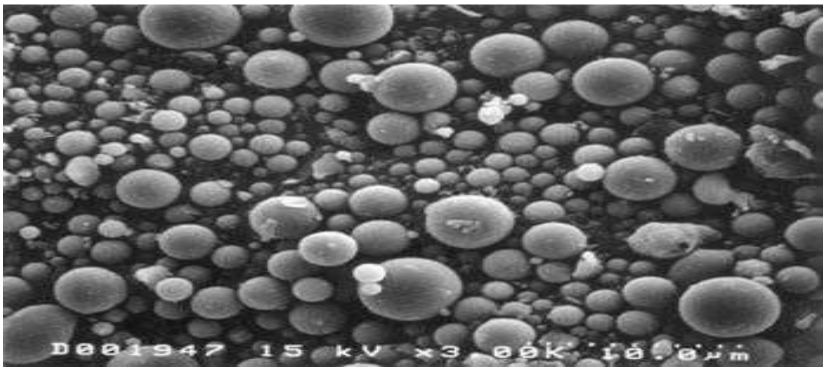


Figure 2: chemical structure of fly ash

2. Production of Fly Ash

Fly slag, otherwise called "pounded fuel fiery remains" in Cinder that falls in the base of the evaporator is called base fiery remains. In cutting edge coal, fly fiery remains is for the most part caught by electrostatic precipitators or other molecule filtration hardware before the pipe gasses come to the stacks. Contingent on the source and cosmetics of the coal being shouldered, the parts of fly slag differ impressively. However all fly fiery remains incorpocrates significant measures of silicon dioxide (SiO_2) (both undefined and crystalline), aluminum oxide (Al_2O_3) and calcium oxide (CaO), the principle mineral mixes in coal-bearing rock strata.

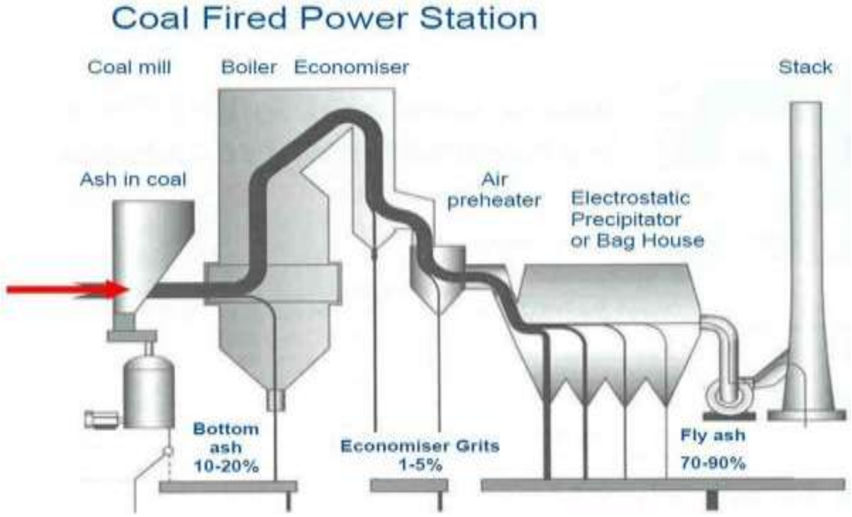


Figure 3: Production process of fly ash.

Constituents rely on the particular coal bed cosmetics however may incorporate one or a greater amount of the accompanying components or substances found in follow fixations (up to hundreds ppm): arsenic, beryllium, boron, cadmium, chromium, hexavalent chromium, cobalt, lead, manganese, mercury, molybdenum, selenium, strontium, thallium, and vanadium, alongside little convergences of dioxins and PAH compounds [4].

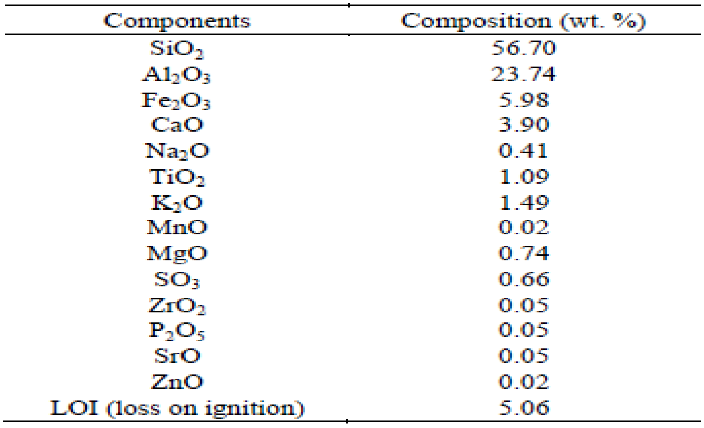
Previously, fly fiery debris was mostly discharged into the air, yet air contamination control authorisations now require that it needs to be caught preceding discharge by fitting contamination control gear. In the US, fly slag is mostly put away at coal power plants or set in landfills. Around 43% is recycled [2], frequently utilized as a pozzolan to create pressure driven bond or water powered mortar and a swap or fractional substitution for Portland cement in solid generation. Pozzolans guarantee the setting of cement and mortar in addition to furnishing concrete with more security from wet conditions [5].

3. Chemical Properties of Fly Ash

The substance synthesis of fly ashes powder relies on upon the attributes and organization of the coal burned in power stations. The substance examination of fly ashes debris by method for X-beam fluorescence (XRF) and spectrometry procedures demonstrates that SiO_2,

Al_2O_3, Fe_2O_3, and CaO are the main components found in the majority of fly ash. The components MgO, Na_2O, K_2O, SO_3, MnO, TiO_2 and C are different. The chemical analysis of various fly ashes has revealed a wide range of structures and components, reflecting the diversity of coal used in power plants across the globe. Table 1[8] shows the usual composition of low-calcium fly ash (10% CaO) that are formed when subbituminous and lignite coal is ignited typically comprise 20–50 weight percent SiO2, 15-20 weight percent Al_2O_3 Al2O3, 15-20 weight percent CaO, 5–10 weight percent Fe_2O_3, and 3–5 weight percent.

Table 1: Chemical composition of fly ash [6]



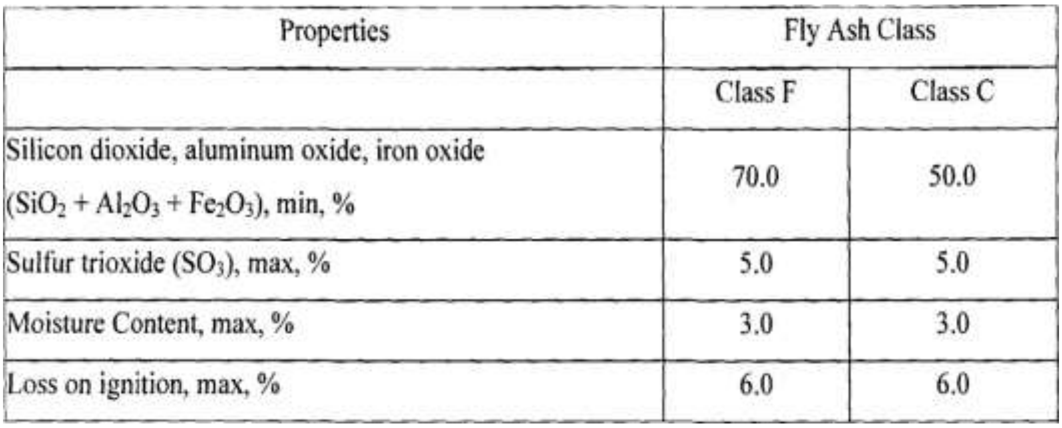
Components	Composition (wt. %)
SiO_2	56.70
Al_2O_3	23.74
Fe_2O_3	5.98
CaO	3.90
Na_2O	0.41
TiO_2	1.09
K_2O	1.49
MnO	0.02
MgO	0.74
SO_3	0.66
ZrO_2	0.05
P_2O_5	0.05
SrO	0.05
ZnO	0.02
LOI (loss on ignition)	5.06

The standard method for testing fly ash, such as cinder, for use as a mineral additive in Portland cement concrete is shown in ASTM C 311. Silica dioxide (SiO2), aluminum oxide (Al2O3), iron oxide (Fe2O3), calcium oxide (CaO), magnesium oxide (MgO), sulfur trioxide (SO3), free CaO, appropriate alkalis, Na2O and K2O loss on ignition at 100°C, and dampness content (moisture content) at 105°C are the elements that need to be resolved, according to this standard. Unfortunately, upon ignition, the weight loss of fly ash at temperatures over 1000°C is attributed to the presence of carbonates, combined water in residual clay minerals, and the combustion of free carbon. The most important section of the LOI is carbon.The amount of water needed to make cement and motors workable depends on the carbon content of.

3.1. Class F and Class C of Fly Ash

The chemical compositions and properties of class C and Class F fly ash in the concrete blends are shown in Table . ASTM C 618 describes the classification of fly ashes. Silicon dioxide, aluminum oxide and iron oxide compose equal or more than 70% of class F fly ashes whereas silicon oxide, aluminum oxide and iron oxide compose around 50% of class C fly ashes as given by ASTM C 618 [7].

Table 2: Chemical composition of class C and class F fly ash [7]



Properties	Fly Ash Class	
	Class F	Class C
Silicon dioxide, aluminum oxide, iron oxide ($SiO_2 + Al_2O_3 + Fe_2O_3$), min, %	70.0	50.0
Sulfur trioxide (SO_3), max, %	5.0	5.0
Moisture Content, max, %	3.0	3.0
Loss on ignition, max, %	6.0	6.0

4. Physical Properties of Fly Ash

Fly ash remains is recognized that it is a fine-grained material comprising for the most part of round particles. Some types of fly ash similarly contain unpredictable of precise particles. The span of particles fluctuates relying upon the sources. Some ashes might be better or coarser than Portland cement particles. Figure 4, Figure5 and Figure6 demonstrates the cleaned segments of subbituminous and lignite fly cinders' filtering electron magnifying lens (SEM) micrographs.

Figure 6 demonstates an auxiliary electron SEM picture of bituminous fly cinder particles. Apart of these particles give off an impression of being strong, while some bigger particles have all the earmarks of being segments of meager, empty circles containing numerous littler particles.

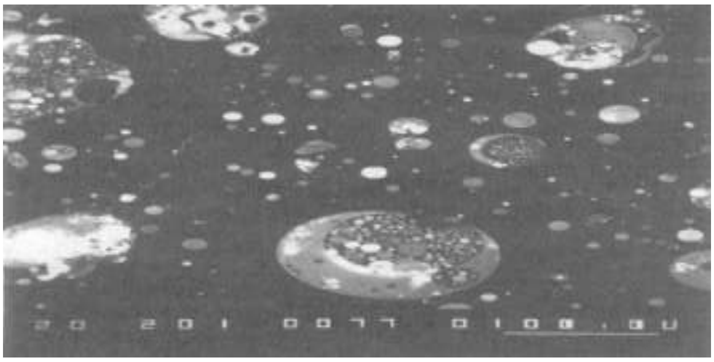


Figure 4: SEM micrograph of a subbituminous ash (Backscattered electron image of a polished section of the dispersed sample).

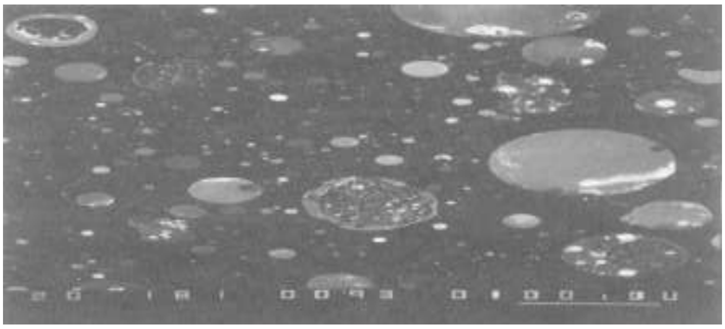


Figure 5: SEM micrograph of a lignite fly ash (Backscattered electron image of a polished section of the dispersed sample).

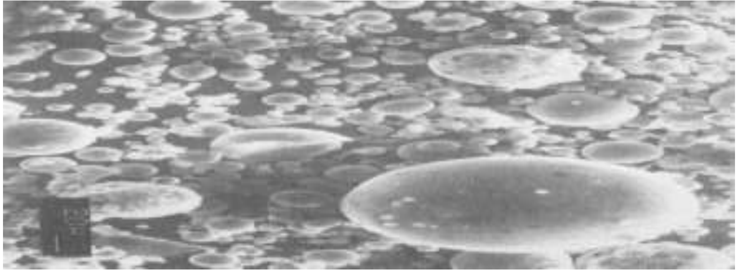


Figure 6: SEM micrograph of a bituminous ash (Secondary electron image of the sample.

4.1. Fineness

Fly ashes, or fly fiery debris, are often estimated for fineness using both dry and wet sieving procedures. As with ASTM method C430, ASTM assignment C311-77 specifies measuring the example held when wet sieved on a 45 lm strainer; nevertheless, in this case, an agent test of the fly fiery debris of distinctive pozzolan is used in place of water driven concrete in the determination. A method developed at CANMET can be used for dry sieving on a 45 lm sifter.

A few countries use the following actions to ascertain the greatest extreme build-up (in rate) held on a 45 lm strainer. SEM and molecular size analysis results show that fly powder shifts are circular and adjusted.

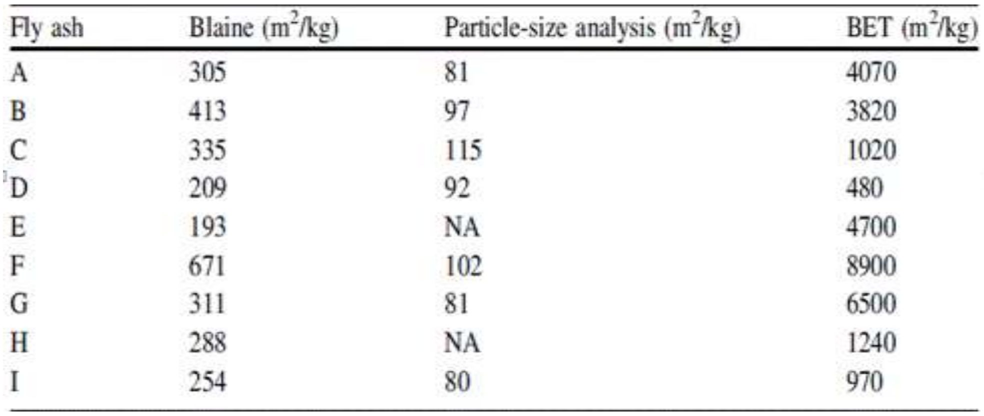
As a rule, fly ashes contain particles of lm width. Mehta [12], utilizing a X-beam sedimentation strategy, reported molecule size appropriation information for a few U.S. fly powder. Mehta found that high-calcium fly ashes were better than the low calcium fly ashes, meaning (HLFA) usually has fineness more than the (LLFA) and he related this distinction to the nearness of bigger measures of antacid sulphates in high-calcium fly ashes.

4.2. Specific Surface Area

The particular surface region of fly powder, which is the zone of a unit of mass, is quantifiable by various systems, which measures the resistance of compacted particles to a wind current. ASTM C 204 portrays this technique for the estimation of the surface zone of Portland bond. Molecule size investigation can likewise be utilized for the determination of the particular surface zone of fly cinder; a laser molecule size analyser is typically utilized for the estimation [9].

The Brunauer–Emmett–Teller (BET) nitrogen assimilation system has additionally been utilized for deciding the particular surface area of the particles, yet the outcomes got by this strategy are typically higher than the outcomes got by the Blaine particular surface-region procedure or molecule size investigation. utilized the Blain procedure, molecule size investigation, and the BET method to measure and figure the particular surface territory of different fly cinders[10]. The aftereffects of their examination are appeared in Table 3.The particular surface qualities measured by the BET method are higher than the qualities got with the Blaine strategy and molecule size investigation. This vast distinction is because of the face that BET strategy measures the totality of voids in the surface of particles.

Table 3: Specific surface areas of nine fly ashes, measured by three different methods.

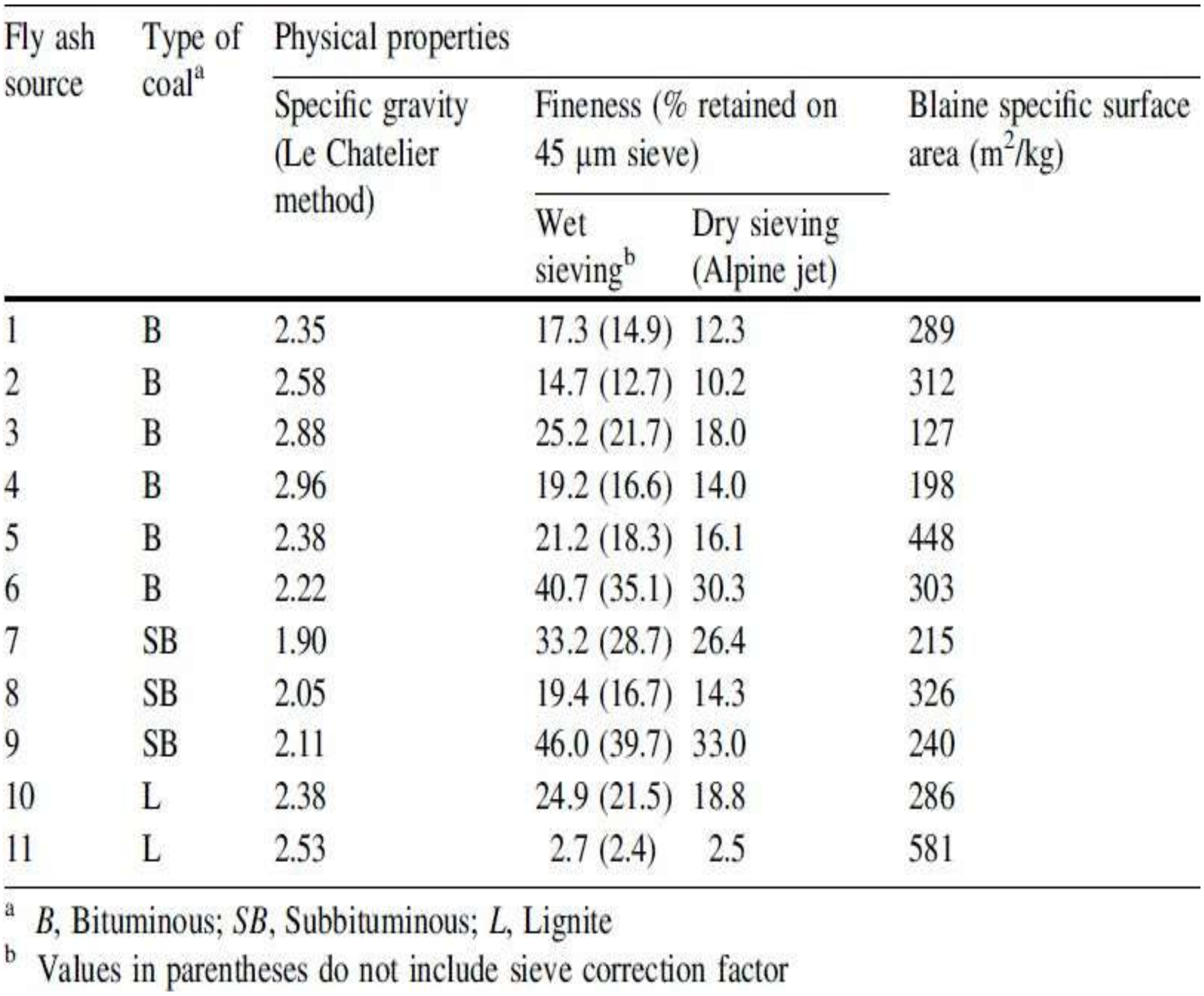


Fly ash	Blaine (m^2/kg)	Particle-size analysis (m^2/kg)	BET (m^2/kg)
A	305	81	4070
B	413	97	3820
C	335	115	1020
D	209	92	480
E	193	NA	4700
F	671	102	8900
G	311	81	6500
H	288	NA	1240
I	254	80	970

4.3. Specific Gravity

The specific gravity of hydraulic cement is resolved by ASTM C 188.This test lools strategy can similarly be appear utilized to decide the specific gravity of fly ashes. Specific gravity of various fly ashes fluctuates over a wide range, similar to the next physical properties. In the CANMET examination of 11 fly ashes, the specific gravity went from a low estimation of 1.90 for subbituminous fiery remains (ash) to a high estimation of 2.96 for an iron-rich bituminous powder. Three subbituminous ashes had a nearly low specific gravity of *2.0, and this recommended empty particles, were available in critical extents in the three types of ashes see Table 4.

Table 4: Specific gravities of fly ash.



Fly ash source	Type of coal[a]	Physical properties			
		Specific gravity (Le Chatelier method)	Fineness (% retained on 45 μm sieve)		Blaine specific surface area (m^2/kg)
			Wet sieving[b]	Dry sieving (Alpine jet)	
1	B	2.35	17.3 (14.9)	12.3	289
2	B	2.58	14.7 (12.7)	10.2	312
3	B	2.88	25.2 (21.7)	18.0	127
4	B	2.96	19.2 (16.6)	14.0	198
5	B	2.38	21.2 (18.3)	16.1	448
6	B	2.22	40.7 (35.1)	30.3	303
7	SB	1.90	33.2 (28.7)	26.4	215
8	SB	2.05	19.4 (16.7)	14.3	326
9	SB	2.11	46.0 (39.7)	33.0	240
10	L	2.38	24.9 (21.5)	18.8	286
11	L	2.53	2.7 (2.4)	2.5	581

[a] *B*, Bituminous; *SB*, Subbituminous; *L*, Lignite

[b] Values in parentheses do not include sieve correction factor

5. Fresh Mix Properties of Concretes Containing Fly Ash

The influence of fly ash on fresh mix properties such as water requirement, workability, bleeding, air entrainment, setting time, heat of hydration, finishing and curing of concrete containing fly ash will be explained in this section of the report.

5.1. Water Requirement and Workability

As shown in Figure 7 and Figure8, usage of good quality fly ash consisting of high fineness and low carbon content in Ordinary Portland cement decreases the water requirement of concrete and enables the same workability as OPC concrete with lower water content. As fly ashes get coarser or the carbon content increases, water requirement increases and it can even be more than the water required for OPC concrete as shown in Figure 7 and Figure 8.

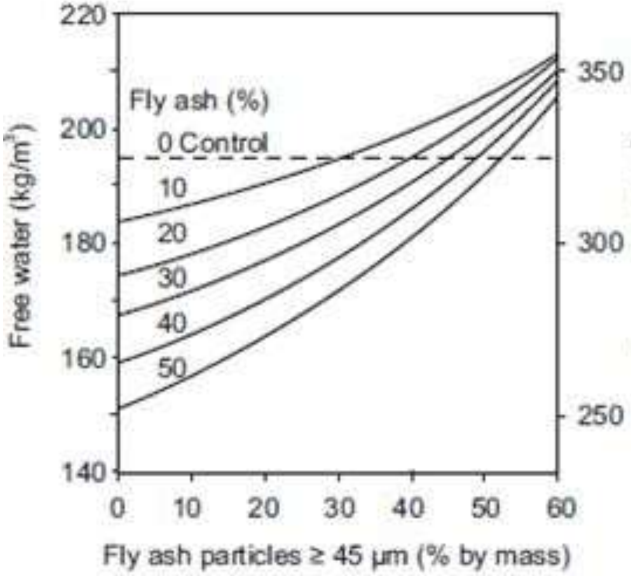


Figure 7: Effect of fineness of fly ash on water demand of concretes proportioned for equal slump [11].

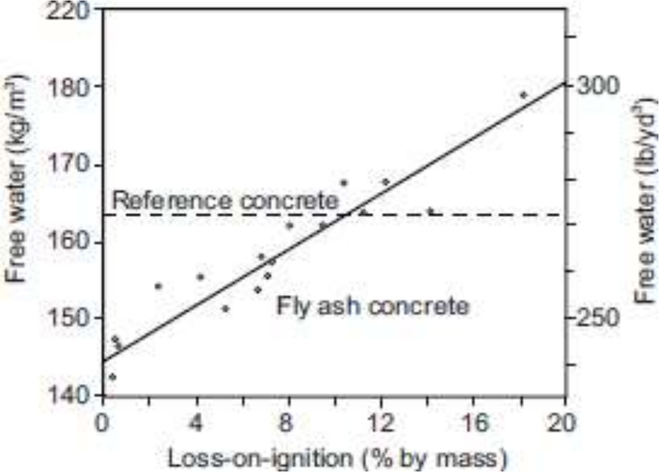


Figure 8: Effect of fly ash loss-on-ignition on water demand of concretes proportioned for equal slump [12].

Exact value of reduction in water content cannot be obtained since it depends on other mix parameters but it is estimated roughly that for 3% reduction in water content, 10% fly ash is required.

Mix proportioning such as amount of water, amount and type of cementing material, aggregate grades, chemical admixtures and amount of entrained air has a critical role in the fresh mix properties of fly ash concrete. As mentioned earlier in this section, usage of fly ash in fly ash concrete improves workability if the mixture is well proportioned. At a given slump, this results in better consolidation and flow when vibration is induced. Moreover, according to Best [13], usage of fly ash results in improved cohesiveness and reduced segregation due to rounded fly ash particles which makes pumping of fly ash concrete easier.

5.2. Bleeding

According to Gebler [14], usage of fly ash reduces the amount and rate of bleeding due to reduced water requirement. Before the finishing stage of exposed slabs, exclusive care is required to determine whether if the bleeding has stopped.

Bleeding in fly ash concrete can be eliminated by using high concentrations of fly ash with low amounts of water but in a case where the probability of rapid surface moisture evaporation is high, immediate finishing and protection is required to prevent plastic shrinkage cracking as given by ACI 305 , Hot Weather Concreting guidance.

If fly ash is used inside concrete with high water amounts, bleeding and so segregation will increase when compared with OPC concrete.

5.3. Air Entrainment

Requireme nt for air-entraining admixtures increases as either the carbon content of fly ash or the fly ash content in concrete increases (e.g. low calcium fly ashes (Class F)) due to unburnt carbon absorbing the air-entraining admixture. It was shown by Gebler [14] that the rate of air loss increases as air-entraining admixture dose in concrete increases

Loss-on-ignition can be used as an indirect method for carbon content measurement of fly ash.

According to Pistilli [15], smaller air entrainment doses are required for high calcium fly ashes whereas bigger air entrainment doses are required for low calcium fly ashes (Class F). Moreover, less admixture dose might be needed for mixes with some of the class C fly ashes than mixes without any fly-ash addition.

5.4. Setting Time

Setting time of the fly ash mixed concrete depends on amount and type of cement, water to binder ratio, amount and type of chemical admixtures, temperature of concrete and amount and type of fly ash used in the mixture. As shown in Figure 9 provided by Concrete Society, initial and final setting times of concretes are delayed by low calcium fly ashes.

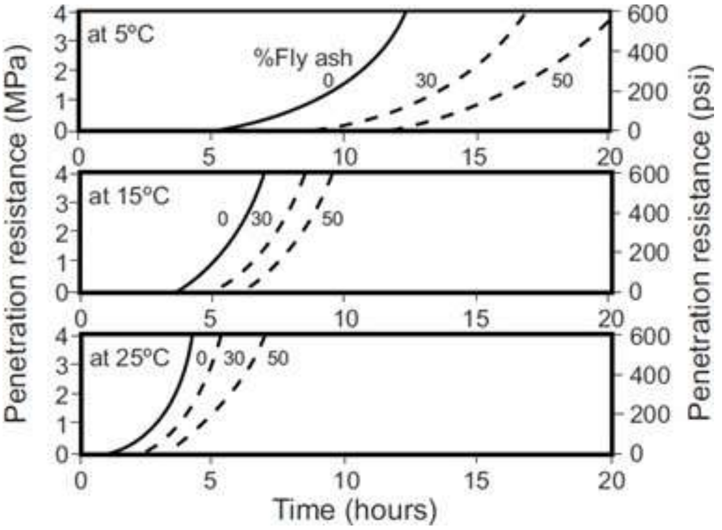


Figure 9: is to be equal strength at 28 days and workability with setting concretes proportioned equally is effected by the temperature for the penetration resistance.

It can be concluded from Figure 9 that retardation in setting times caused by fly ash is lower in higher temperatures.

Significant delays can be induced to initial and final setting times if high concentrations of fly ash are used in low temperatures. These conditions will adversely affect placement and finishing of fly ash concrete so fly ash content must be limited when fly ash concrete is going to be casted at low temperatures. These effects can be avoided completely or up to a certain degree by:

- Using set-accelerating admixtures
- Using ASTM C150 Type III cement
- Inducing heat to the concrete mixture when casting to increase initial setting temperature by means of using hot water and/or aggregates

Initial and final setting times are less delayed with high-calcium fly ashes than low-calcium fly ashes mainly due to higher rates of hydraulic reactivity of fly ash with higher calcium contents. However as mentioned by Wang [16] and Roberts [17], high calcium fly ashes with particular binder-admixture combinations must be used carefully as they can either cause rapid setting or extremely delayed setting. Due to this, testing must be done not only with high- calcium fly ashes but with all fly ashes at fly ash cement production plants in order to determine the effects of fly ash type and content on concrete setting behaviours at different temperatures.

5.5. Heat of Hydration

Mixing fly ash with concrete reduces the heat produced during hydration. As shown in the Figure10 provided by Mustard [18], 30% replacement of OPC with class F fly ash reduced the maximum temperature rise by 15°C in the construction of the Otto Holden Dam in Northern Ontario.

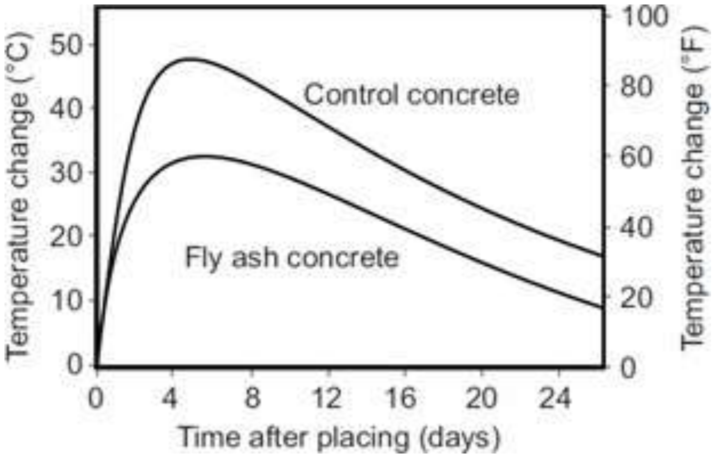


Figure 10: Effect of fly ash on temperature rise in concrete [18].

Maximum temperature rise in fly ash concrete in large quantities of concrete mixes is mainly affected by:

- Quantity and type of OPC
- Quantity and type of fly ash
- Casting temperature of the initial mix

Studies done by Langley [19] show that, in order to minimize self-generated temperature rises, higher fly ash to OPC ratios are used in fly ash concretes. This effect is also shown in studies done by Bisaillon [20] by using high volume fly ash concrete with type F fly ash. This property can be very beneficial if early age strengths are not desired in order to control temperature rise in large quantity casting.

On the other hand, rate of heat development increases as the calcium content of the fly ash increases and can result in little or no decrease in the heat of hydration if high calcium fly ashes are used.

Studies done by Barrow [21], show that high calcium fly ashes delay the initial rate of heat development but has no effect on the maximum temperature rise.

5.6. Finishing and Curing

Delaying of the setting time caused by fly ash in concrete may result in delaying of the finishing operations. Pozzolanic reactions of fly ash are slower than cement hydration reactions at normal temperatures and so special care must be given to fly ash concrete in the curing stage in order to realize full benefits of the incorporated fly ash.

Moist curing for 7 to 14 days or placement of curing membrane after moist curing for 7 days are recommended for fly ash concretes with high fly ash quantities. If one of the mentioned methods cannot be applied, fly ash content must be limited.

6. Hardened Properties of Concretes Containing Fly Ash

6.1. Compressive Strength of Fly Ash Concrete

Compressive strength is an important mechanical property of concretes since it is the major reason concrete is selected as the main structural material in the vast majority of buildings. The load bearing structural concrete should have a specified compressive strength. The use of fly ash concrete can influence the compressive strength in various ways. Similar to the case for other cementitious composite materials, the compressive strength of concretes with fly-ash replacement depends on many factors, including the mix design parameters such as binder content, fly ash replacement level, the aggregate grading, as well as the pozzolanic reactivity of the fly ash (as a function of chemical nature and fineness), curing conditions and the age of curing. In order to analyze the influence of each factors, some of the other factors has to be constant.

Since the strength development mechanism of fly-ash added concrete involves pozzolanic reactions, there is a deviation from the strength development trend that is observed for OPC concrete. The addition of fly ash as a cement replacement has an influence on the early- age strength of concrete. As more Class C fly ash is added to concrete, a reduction of the early- age strength can be observed (Figure 11) [23]. However due to hydration kinetics, the long-term compressive strength development shows a different trend, where the strength of fly-ash added concrete will be equal to that of OPC concrete at later ages and finally will exceed that of OPC concretes, given that proper curing aids were sustained [22, 23]. This breakeven point changes with the amount of fly ash addition as well as the amount of calcium present in the fly ash (Figure11) [23].

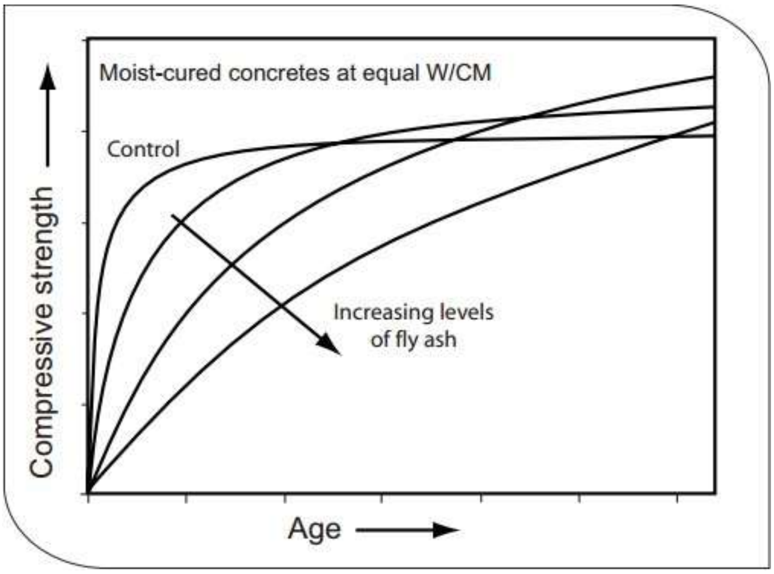


Figure 11: The general influence of fly ash on compressive strength development of concrete [36].

The retardation effect observed as the low early strength in fly-ash-concretes was related to the reaction of C_3S and C_3A phases. This is expressed as an induction period in C_3S hydration which is caused by the dissolution of the aluminate ions, organics and other species from fly ash into the aqueous phase, delaying the nucleation and crystallization of $CaOH_2$ and CSH phases. A rather physical cause of this effect was also mentioned as the adherence of the fly ash particles on cement grains, blocking the interaction and reducing the initial reactivity. Literature also mentions findings of the microscopically studies about the large deviations in the strength developments that, the initiation of the pozzolanic reactions may take 3 to 28 days depending on various factors .

Partial replacement of cement and fine aggregates by fly ash results in concretes with early strengths similar to OPC concrete, however the later ages show increased compressive strength for FA concretes. If fly ash is used to partially replace the aggregates, regardless of the strength development period, the compressive strength increases [24]. However, there are some studies which report a definite and consistent reduction in compressive strength up to 91 days of hydration, when the fly ash addition ranged from 20% to 60% of cement, although no explanation was made on the cause of this phenomenon [26]. The compressive deformation of fly ash concrete was also reported to be better .

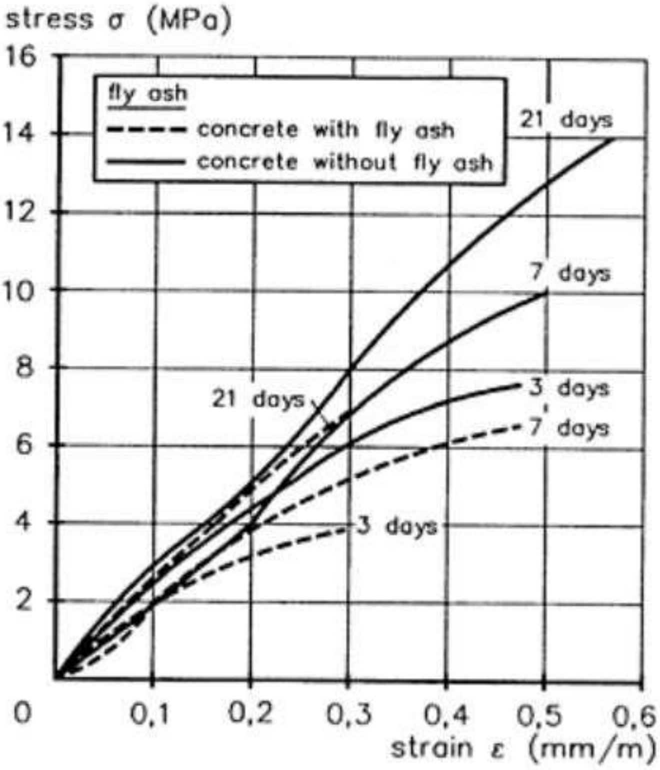


Figure 12: Compressive deformation curves of concretes with and without fly ash replacements [22].

The influence of fly ash addition on the compressive strength of concrete is not only dependent on the fly ash content, but also strongly dependent on the fineness of the fly ash being added. In a study done by Shaikh et al. [27], it was found that a 8% ultra-fine fly ash (mean size of 3.4 μm) addition had improved the compressive strength of concrete, up to 50% and 100% for 3 and 7 days respectively, where an almost 50% increase was obtained at 90 days [27]. It can be seen in their comparison (Figure 13) that the addition of coarse fly ash, with even higher replacement levels would result in similar or lower compressive strengths. However heavy filling of ultrafine fly ash would also deteriorate the compressive strength.

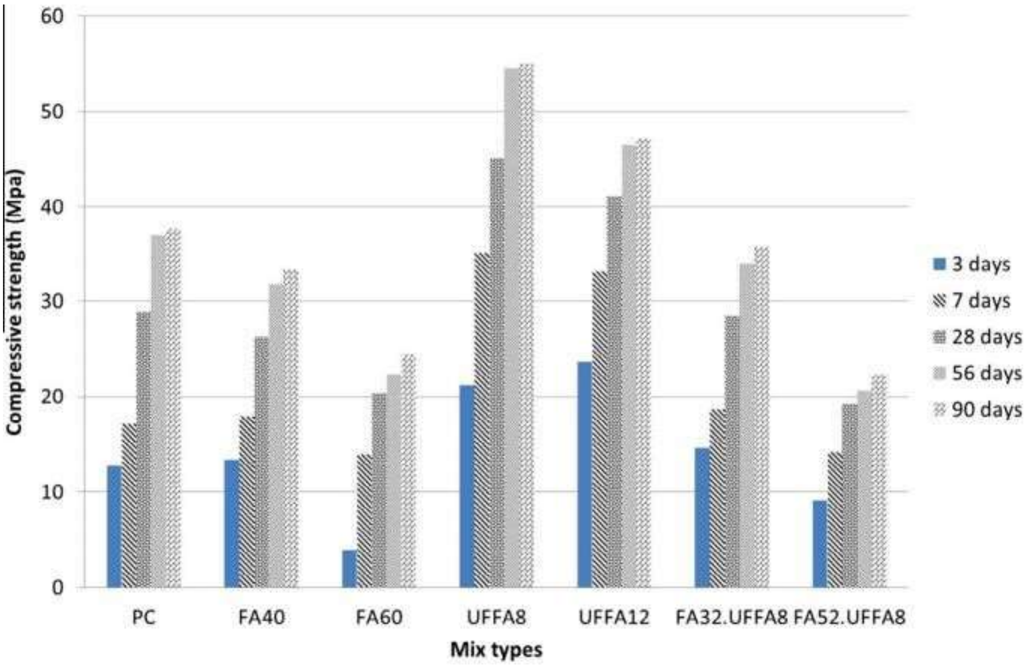


Figure 13: Compressive strength comparison of concretes containing fine and ultrafine fly-ash [27]**.**

Another important parameter that influences the early-age strength development of fly ash concretes is temperature. Since pozzolanic reactions are considerably sensitive to temperature, significant improvements can be realized for the 30% fly-ash replaced concrete when compared with the control OPC concrete, at high temperatures. These improvements are much more pronounced than that observed at standard curing regimes (Figure 14) [23].

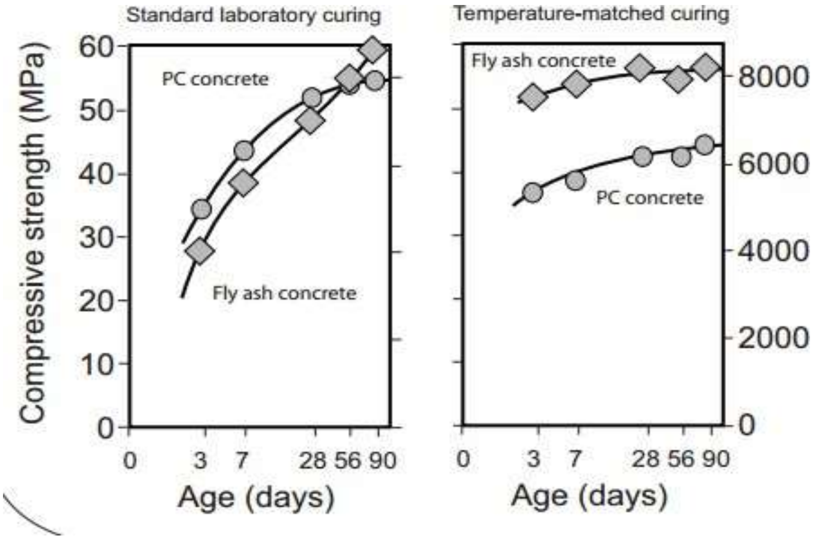


Figure 14: The influence of temperature on compressive strength [23]**.**

6.2. Durability and Microstructural Aspects of Fly Ash Concretes

Similar to other materials, the macro properties of fly ash added concretes are determined by the morphology and microstructural features. When FA is used for partially replacing cement, the microstructure of the resulting concrete contains features from both cement hydration and pozzolanic reactions. Instead of a deep description of all the features, some remarks on the microstructure will be given in this section to keep the discussion at a reasonable scope, close to the hardened properties.

Fly ash undergoes a pozzolanic reaction where it reacts with Calcium Hydroxide (CH) during cement hydration, where Calcium Aluminate Hydrate (CAH) and Calcium Silicate Hydrate (CSH) are formed. By this way a denser matrix is formed, resulting in a pronounced strength and improved durability [27]. The denser matrix usually comes with a less permeable structure. In literature it was mentioned that the pastes with 30% fly ash replacement had showed significantly lower permeability of water, compared to plain-OPC pastes, given that the pozzolanic reactions were completed to a sufficient level. It was stated that this trend was parallel to the consumption of CH. It was also mentioned that the pore structure (both pore size distribution and continuity of pores) were influence by this behaviour . These aspects were also observed by the experimental studies where volume of permeable voids and chloride ion penetration was decreased by addition of a small amount of ultra-fine fly ash as cement replacement, although heavily loading ultra-fine and relatively coarser fly ash had later caused detrimental effect, which was also observed at the compressive strength results of the same study [27]. Similar trends for chloride ion penetration were also observed in other studies.

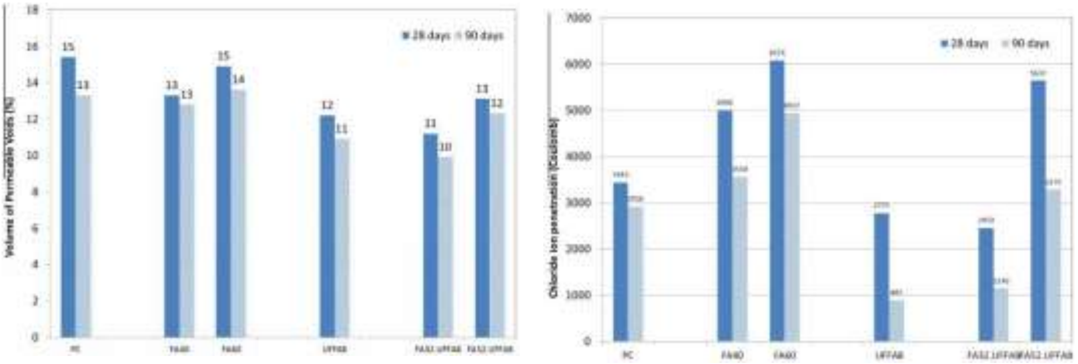


Figure 15: Volume of Permeable voids (left) and Chloride Ion Penetration (Right) of concretes with various fly ash cement replacement levels [27]**.**

6.3. Creep

Creep is a plastic permanent deformation of structure under sustained loading which basically implies the long term pressure or stress that can change the shape of the concrete. Creep of concrete is affected by many parameters and the effect of fly ash on creep will relate to how the influence is accounted and measured. According to studies conducted by Lane and Yuan [28], fly ash concrete may exhibit higher creep than ordinary Portland cement concrete if exposed to loading at early age. This may be attributed to the slow pozzolanic reaction of fly ash particles which retards the early age compressive strength of concrete. However, if both Portland cement and fly ash blended concretes are loaded at an age that they have the same compressive strength, fly ash concrete found to exhibit less creep due to its continued strength gain.

The study also conducted on the creep of high volume fly ash (HVFA) concrete and the creep of HVFA concrete tends to be lower than control concrete with equal strength. The reason for the lower creep of HVFA concrete is due to the presence of unreacted fly ash content. Moreover, high aggregate content with very low water and paste contents are basic properties that reduce the creep of concrete with high volume of fly ash.

6.4. Shrinkage

The water content, water to cement ratio and volume of aggregates are the major parameters affecting drying shrinkage of concrete. Compared to an equivalent Portland cement concrete, use of fly ash reduces the water demand which respectively reduces the volume of mixing water which as result reduces the shrinkage. It is stated in the previous studies that use of high volume of fly ash in concrete reduced the shrinkage of conventional concrete which was attributed to the low levels of water usage during production of HVFA concrete [23].

Cengiz Duran Atis also carried out an experimental study to investigate the effect of high volume fly ash on shrinkage properties of conventional concrete . Mechanical dial gauge was used to measure the changes in length of 50x50x200 mm concrete prisms with 1/400 sensitivity. Two prisms were cast for each mixture which the mix proportions are given below and were placed into curing room at 20 degrees and 65% relative humidity. First measurements were taken just after the concrete specimens were placed in the drying environment. For each age, two specimens were used and measurements were continued for six months and finally the averages of two specimens were taken as the shrinkage of concrete. The result are given below in Table6 and according to results, HVFA concrete found to have lower shrinkage value than conventional Portland cement concrete at all ages. The results of the specimens illustrate that concrete specimens with 70% high volume fly ash replacement had a lowest shrinkage values followed by 50% HVFA replacement medium shrinkage and lastly control specimens had highest shrinkage values. This improvement in terms of shrinkage is not only a function of low water ratios; it is also due to the reduction in the amount of cement past in a unit volume of concrete because of high volume of fly ash replacement with cement.

Table 5: Mix proportions for Cubic Meter of Concrete

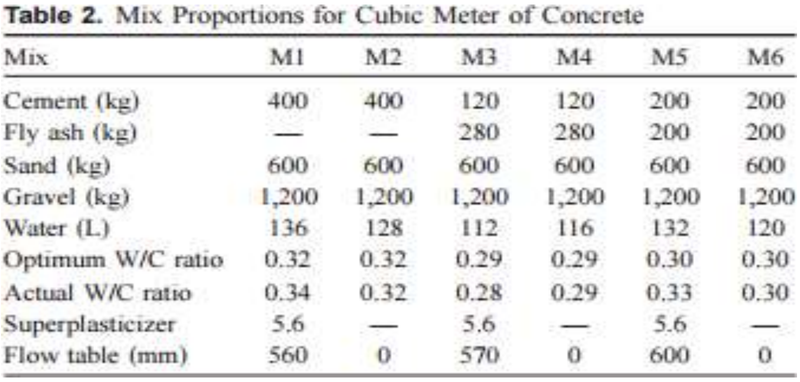


Table 2. Mix Proportions for Cubic Meter of Concrete

Mix	M1	M2	M3	M4	M5	M6
Cement (kg)	400	400	120	120	200	200
Fly ash (kg)	—	—	280	280	200	200
Sand (kg)	600	600	600	600	600	600
Gravel (kg)	1,200	1,200	1,200	1,200	1,200	1,200
Water (L)	136	128	112	116	132	120
Optimum W/C ratio	0.32	0.32	0.29	0.29	0.30	0.30
Actual W/C ratio	0.34	0.32	0.28	0.29	0.33	0.30
Superplasticizer	5.6	—	5.6	—	5.6	—
Flow table (mm)	560	0	570	0	600	0

Table 6: Drying Shrinkage (Microstrain) of Concrete

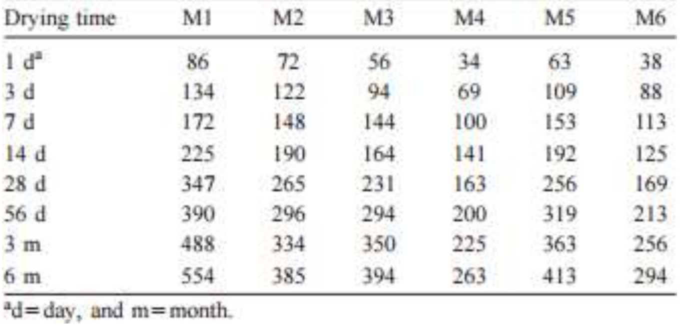


Table 6. Drying Shrinkage (Microstrain) of Concrete

Drying time	M1	M2	M3	M4	M5	M6
1 d[a]	86	72	56	34	63	38
3 d	134	122	94	69	109	88
7 d	172	148	144	100	153	113
14 d	225	190	164	141	192	125
28 d	347	265	231	163	256	169
56 d	390	296	294	200	319	213
3 m	488	334	350	225	363	256
6 m	554	385	394	263	413	294

[a] d = day, and m = month.

6.5. Alkali-Silica Reaction

Alkali-silica reaction is one of the most important concerns of concrete because reactive silica materials are take part in aggregates. During this reaction, specific forms of silica included in aggregates react with alkali hydroxide in concrete to form a gel which adsorbs water from the surrounding cement paste or the environment and swells. As a result, these gels can exert expansion pressure enough to damage concrete .

Low-calcium (Class F) has a well-known property of controlling the damage to concrete due to alkali-silica reaction at replacement levels of 20% to 30%. This effect may be attributed to the decreased alkali hydroxide concentration in the pore solution due to fly ash addition. The figure below shows the expansion result of concrete specimens conducted by Michael Thomas [23]. All specimens contain high-alkali cement, a reactive siliceous limestone coarse aggregates and different fly ashes at 25% replacement level. The casted specimens were stored in water at 38 degrees for 2 years before tested. In the graph, the expansion of concrete is plotted versus calcium oxide content of fly ash. As it can be seen be from the graph, fly ashes with less than 20% and less than 4% calcium oxide and alkali contents respectively found to have effect of controlling damaging expansion (expansion larger than 0,04%). High-alkali/high- calcium (Class C) fly ashes with calcium oxide more than 20% found to less effective than Class F fly ashes and the expansion of concrete specimens were increased with increase in the calcium oxide content of fly ash.

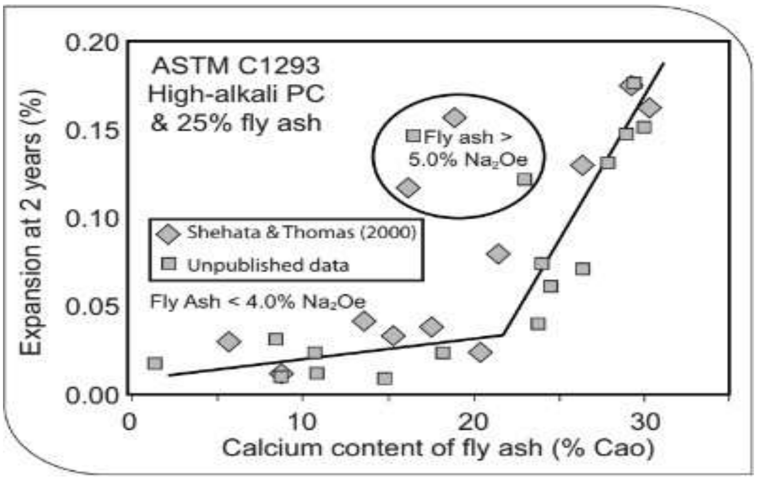


Figure 16: Effect of fly ash composition on expansion of concrete (reactive siliceous limestone coarse aggregate and 25% fly ash) [23].

However, the readings of the Figure 17 show that high calcium fly ashes can be used to control expansion when a replacement level is over 50%.

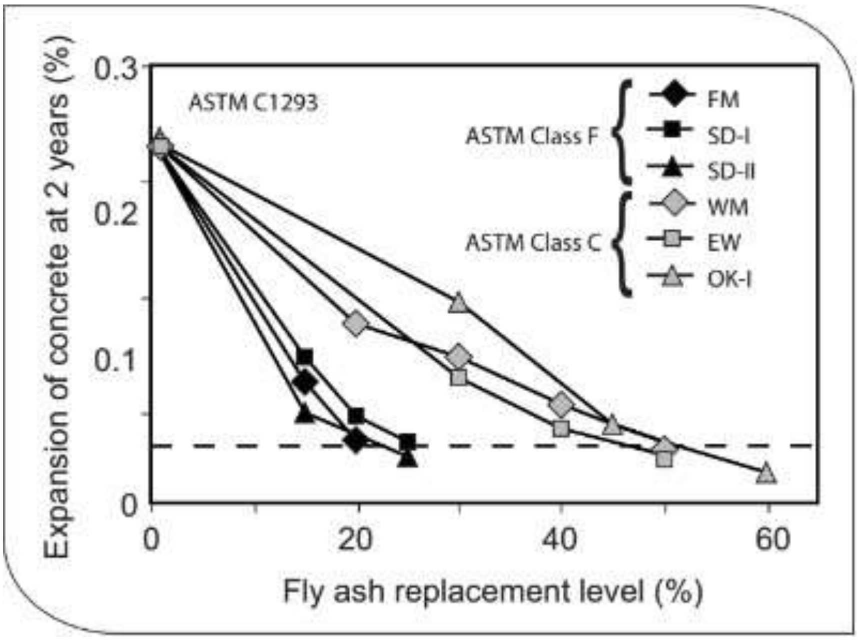


Figure 17: Effect of fly ash composition and level of replacement on expansion of concrete (reactive siliceous limestone coarse aggregate) [23]**.**

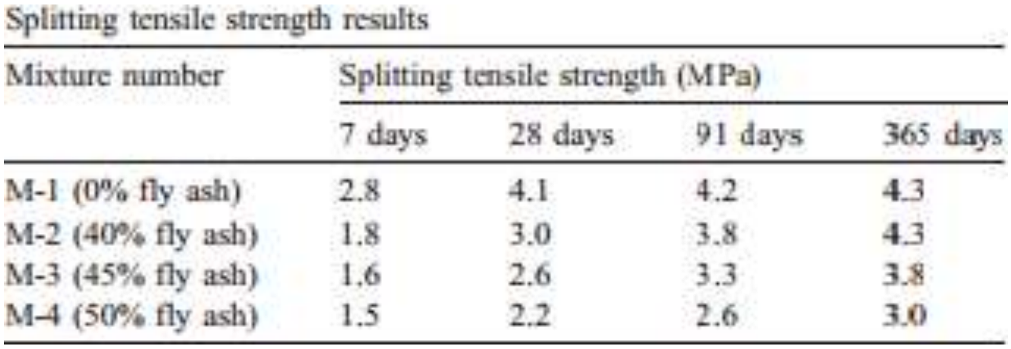
The parameters effect the level of fly ash replacement required in order to overcome deleterious expansion are given below;

- High calcium and alkali content of fly ash
- Low silica content of fly ashes
- High aggregate reactivity
- Increased alkali availability of Portland cement
- High alkali content in surrounding and environment

6.6. Splitting Tensile and Flexural Strengths

Based on the experiment conducted by Rafat Siddique, the concrete specimens were prepared with three different fly ash replacement ratios (40%, 45% and 50%) and tested at 7, 28, 91 and 365 days. Table 7 shows the results obtained and according to results, splitting tensile strength of concrete specimens decreased with an increment in fly ash content but increased with age. However, the differences between control specimen and fly ash specimens were large, these differences became smaller with an increase in age which can be attributed to slow pozzolanic reaction of fly ash particles. The similar results were also observed for flexural strength of the specimens which were prepared at the same way with splitting tensile strength and tested at the same ages. The results for flexural strength are given below in Table 8 and like splitting tensile strength, flexural strength of concrete specimens were increased with an increase in age due to same reason.

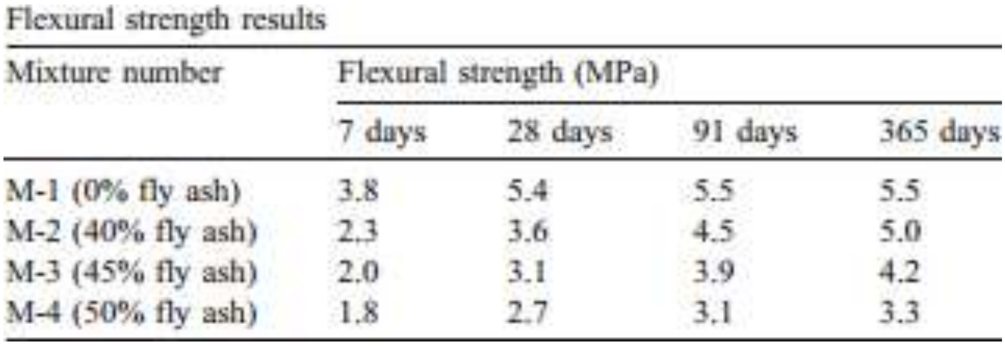
Table 7: Splitting tensile strength results [30].



Splitting tensile strength results

Mixture number	Splitting tensile strength (MPa)			
	7 days	28 days	91 days	365 days
M-1 (0% fly ash)	2.8	4.1	4.2	4.3
M-2 (40% fly ash)	1.8	3.0	3.8	4.3
M-3 (45% fly ash)	1.6	2.6	3.3	3.8
M-4 (50% fly ash)	1.5	2.2	2.6	3.0

Table 8: Flexural strength results [30].



Flexural strength results

Mixture number	Flexural strength (MPa)			
	7 days	28 days	91 days	365 days
M-1 (0% fly ash)	3.8	5.4	5.5	5.5
M-2 (40% fly ash)	2.3	3.6	4.5	5.0
M-3 (45% fly ash)	2.0	3.1	3.9	4.2
M-4 (50% fly ash)	1.8	2.7	3.1	3.3

7. Use of Fly Ash in concrete

7.1. Ready mixed concrete

According to surveys took place in United Stated in 1983 and 1989, there are 61% and 9% increase in the number of companies use at least some fly ash and the number of concrete produced containing fly ash respectively. This increase could be attributed to technical benefits, reduced cost, increased requirement for high strength concretes (52 MPa or greater), improvements in the properties of fly ash according to standards and encouragement by governments for use of fly ash. The other advantages in case of concrete producers is that concretes containing fly ash are easy to pump higher and further at higher speeds with less bleeding and segregation .

7.2. Concrete Pavement

Due to study took place in 32 states in 1992, it was found that use of fly ash in concrete pavement was permitted. Problems with increased air entrainment agent and increased transportation costs were identified as quality control and logistic problems. However due to its higher flexural strength and reduced cement content and most importantly availability of quality of fly ash in most areas, use of fly ash was extended to maximum level. An experimental study was also took place to evaluate the strength, creep, finish ability and long term wear resistance of fly ash concrete pavements and as a result all pavements constructed found to perform well.

7.3. Mass Concrete

Improved sulfate resistance and alkali to aggregate reaction, reduced heat of hydration (reduces the risk of thermal crack inered in mass concrete constructions. Corps of Engineers and private engineers were constructed at least 100 major dams and locks by considering these benefits of fly ash and there are only little numbers of dams built in United States built without use of these industrial by-product other pozzolans .

8. Examples of Fly Ash Concrete Structures

As explained in the earlier sections of this report, use of fly ash in concrete has many beneficial effects to fresh and hardened properties if it is designed correctly and necessary precautions are taken. It has a wide range of applications in real world ranging from building foundations to high performance and strength structures in the forms of ready-mixed, pumped, roller compacted and precast concretes. Some of the case studies are listed below as:

- Lower Notch Dam, Ontario

Figure 18: The Lower Notch Power Generating Station: (left) general overview; (left) spillway as it appeared

- St. Clair River Tunnel, Ontario-Michigan
- Bayview High-Rise Apartment Complex, Toronto
- York University - Computer Sciences Building, Vancouver

Figure 19: York University - Computer Sciences Building [31].

Use of fly ash in these structures were mainly due to controlling alkali-silica reactions, increasing chloride resistance, increased usage of recycled materials and easier placing-finishing of concrete.

9. Conclusions

- Depending on their chemical composition, fly ashes can be categorized as Class F and Class C.
- The fineness, shape, particle size distribution, and density of the fly ash particles are the physical properties that influence the properties of fresh and hardened concrete.
- Use of fly ash as its optimum level decreases water requirement and bleeding by increasing workability while increases air entrainment agent.
- Ultimate compressive strength is equal or higher which depends on fineness and curing conditions.
- Durability increases in conjunction with decrease in permeability.
- Shrinkage and alkali-silica reactions decreases.

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