Utilization Of Fly Ash in Construction Materials : Review

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ABSTRACT

Fly ash is the residue from burning coal in thermal power plant, Wich is the most complex anthropogenic material and if the disposal is improper, it will become environmental pollution. The use of fly ash blended cement and sand mixes is growing rapidly in the construction industry. The purpose of utilizing fly ash is to minimize the cost of fly ash disposal, decrease land provision for fly ash disposal, financial benefits, compensation of processing and disposal costs. Fly ash can replace some rare and expensive natural resources. Fly ash has good performance and environmentally friendly. A systematic literature review is defined as the process of identifying, assessing several existing research sources with the purpose of providing specific research answers. Analysis of the main studies on the utilization of fly ash in construction materials focusing on class C fly ash as a substitute for cement, and class F fly ash is a sand substitute. The chemical composition is highly complete with good pozzolanic. The initial hardening time is reduced between 20 minutes to 260 minutes, final hardening 60 minutes to 260 minutes. Due to high sulfate, class C fly ash takes longer to harden than Class F fly ash. Class C and Class F fly ash with a high aluminosilicate content, and a fine size contributes to the improved workability of concrete. Fly ash can be used as a raw material in various construction industry due it is an oxide-containing material. Fly ash can be utilized for brick producing, ceramic manufacturing, road construction, concrete production and other activities.

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1. INTRODUCTION

Construction industry can be one of the impact in environmental pollution. Continuously usage of cement in concrete can give bad impact to the atmosphere, especially for those related directly to global warming. [1],[2] .The development and the usage of cement mixed with fly ash grow rapidlyin construction industry especially caused by the considerations of cost savings, energy savings, environmental protection and resource conservation.[3] whereas the use of fly ash in high volume, plays a role as a substitute for fine aggregates in rooftile concrete. It is because fly ash is used to replace sands, and minimalize mineral source depletion. [4]. Fly ash is the residue from burning coal in thermal power plant which is categorized as one of the most complex anthropogenic material, and it can cause environmental pollution if the disposal is not proper.[5], [6],[7]. It is because the complex compositions, smooth size, morphology and various particle properties, that cause serious problems with identification, characterization, specification. [6]. fly ash based construction materials have great potential as replacement alternative of Portland cement, because of its good performance and environmentally friendly. [2]

1.1. Review of Literature

a. Fly Ash

In this research, the researcher uses the explanation of fly ash which is made of the residue from burning coal in electric power plant which has a high silica content, has the quality of pozzolan and good hydration.[8]. Fly ash is a material contains the most complex and plenty of anthropogenic, if it is not disposed properly, it can pollute water and soils, disturb the cycle of ecology and cause environmental danger. As described above, high siliceous fly ash is considered as a cementitious ingredient for concrete. This study describes the use of fly ash in mortar and concrete, as a partial replacement for Portland cement and results in significant savings in concrete production costs.[3] Fly ash can also be used as a substitute for fine aggregate in paving and shows good performance.[9].

There are many reasons to increase the amount of fly ash being re-utilized. A few of these reasons are given below. Firstly, disposal costs are minimized; secondly, less area isreserved for disposal, thus enabling other uses of the land and decreasing disposal permitting requirements; thirdly, there may be financial returns from the sale of the by-product or at least an offset of the processing and disposal costs; and fourthly, the by-products can replace some scarce or expensive natural resources.

Utilization of coal combustion by-products, namely fly ash, can be in the form of an alternative to another industrial resource, process, or application. These processes and applications include, but are not limited to, addition to cement and concrete products, structural fill and cover material, roadway and pavement utilization, addition to construction materials as a light weight aggregate, infiltration barrier and underground void filling, and soil, water and environmental improvement. The following is a brief description of each of the previously mentioned alternative uses of fly ash and associated research that has been conducted and how it relates to each alternative use. In this section, the application of fly ash has been discussed.[1]

b. Classification of Fly Ash

The recently classification systems for fly ash that come from, Spain, Bulgary, Netherland, Italy, Turkish country, Greece in this research concluded based on ASTM C618 or EN450 are basically a binary classification (they are C class and F class). Therefore fly ash will be one of these category.

An F class fly ash has calcium under 10 % that usually comes from high rank bituminous coal and anthracite and fly ash are pozzolanic in nature.6 , (it hardens when reacted with Ca (OH) 2 and water. On the contrary a C class fly ash contains more than 10% of calcium that usually comes from The burning of low rank lignite and sub-bituminous coal and this kind of fly ash has the properties of cement (self-hardens when reacted with water) and pozzolanic.[10]

c. Composition of Fly Ash

The chemical composition of fly ash is similar to Portland cement that the activity of pozzolanic is also good. [11] The chemical composition of fly ash is very complete that contains some elements like O, C, Si, Al, Mg, Fe, Ca, K, Na and Ti. And heavy metals : Hg, Pb, As, Cr, Cd, Cu, Zn, Mo, Ba, B and Ni. (Synthesis of high quality zeolites from coal fly ash: Mobility of hazardous elements and environmental applications) here the Table 1. Composition of fly ash. [12]

Table 1. Chemical Composition of Fly Ash in various Countries

Country	%Chemical	Composition									
	SiO_2	Al_2O_3	Fe_2O_3	CaO	K_2O	MgO	SO_3	TiO_2	Na_2O	P_2O_5	MnO	LOI
Australia	31.1-68.6	17-33	1-27.1	0.1-5.3	0.1-2.9	0-2	0-0.6	1.2-3.7	0-1.5	0-3.9	nd	na
Bangladesh	55	24.7	7.7	6.2	1.1	0.7	1.1	na	na	0.9	0.1	na
Bulgaria	30.1-57.4	12.5-25.4	5.1-21.2	1.5-28.9	0.8-2.8	1.1-2.9	0.4-12.7	0.6-1	0.4-1.9	0.1-0.4	0-0.2	0.8-32.8
Canada	35.5-62.1	12.5-23.2	3-44.7	1.2-13.3	0.5-3.2	0.4-3.1	0.2-7.8	0.4-1	0.1-7.3	0.1-1.5	na	0.3-9.7
China	35.6-57.2	18.8-55	2.3-19.3	1.1-7	0.8-0.9	0.7-4.8	1-2.9	0.2-0.7	0.6-1.3	1.1- 1.5	nd	nd
Denmark	48-65	26-33	3.3-8.3	2.2-7.8	na	na	na	na	1.1-2.8	na	na	3.1-4.9
Europe	28.5-59.7	12.5-35.6	2.6-21.2	0.5-28.9	0.4-4	0.6-3.8	0.1-12.7	0.5-2.6	0.1-1.9	0.1-1.7	0-0.2	0.8-32.8
France	47-51	26-34	6.9-8.8	2.3-3.3	na	1.5-2.2	0.1-0.6	na	2.3-6.4	na	na	0.5-4.5
Germany	20-80	1-19	1-22	2-52	0-2	0.5-11	1-15	0.1- 1	0-2	na	na	0-5
Greece	21-35	10-17.9	4.5-8.4	27.3-45	0.4-1	1.5-3.8	4-8.6	na	0.2-1	na	na	3-7
India	50.2-59.7	14-32.4	2.7-16.6	0.6-9	0.2-4.7	0.1-2.3	na	0.3-2.7	0.2-1.2	na	na	0.5-7.2
Israel	45.6-58.6	24.4-34.5	3-6.7	4.9-9.9	0.1	1.6-2.5	0.6-0.8	1.2-1.9	0-0.1	0.8-1.8	na	6
Italy	41.7-54	25.9-33.4	3-8.8	2-10	0-2.6	0-2.4	na	1-2.6	0-1	0-1.5	0-0.1	1.9-9
Japan	53.9-63	18.2-26.4	4.2-5.7	2-8.1	0.6-2.7	0.9-2.4	03-1.4	0.8-1.2	1.1-2.1	na	na	05-2.1
Korea	50-55.7	24.7-28.7	3.7-7.7	2.6-6.2	I.1	0.7-1.1	0.5-1.1	na	na	0.9	0.1	4.3-4.7
Mexico	59.6	22.8	5.6	3.1	1.3	0.9	0.4	0.9	0.5	0	na	na
Netherlands	45.1-59.7	24.8-28.9	3.3-9	0.5-6.8	0.6-2.9	0.6-3.7	0.2-1.3	0.9-1.8	0.1-1.2	0.1-1.5	0-0.I	2.7-8.1
Northern China	43.7	44	3.5	0.9	0.9	0.4	0.7	1.5	0.3	na	na	10
Poland	32.2-53.3	4-32.2	4.5-8.9	1.2-29.9	0.2-3.3	1.2-5.9	na	0.6-2.2	0.2-1.5	0.1-0.9	0-0.3	0.5-28
Russia	40.5-48.6	23.2-25.9	na	6.9-13.2	1.9-2.6	2.6-4	na	0.5-0.6	1.2-1.5	03-0.4	0.2-0.4	na
South Africa	46.3-67	21.3-27	2.4-4.7	6.4-9.8	0.5-1	1.9-2.7	na	1.2- 1.6	0-1.3	03-0.9	0-0.5	na
Spain	41.5-58.6	17.6-45.4	2.6-16.2	0.3-11.8	0.2-4	0.3-3.2	0.1-2.2	0.5- 1.8	0-1.1	0.1-1.7	0-0.I	1.1-9.7
Spain	41.5-58.6	17.6-35.6	2.6-16	0.8-11.8	0.4-4	0.9-2.5	0.1-2.2	0.5- 1.6	0.2-0.8	0.1-1.7	0-0.I	1.1-5.2
Turkey	37.9-57	20.5-24.3	4.1-10.6	0.2-27.9	0.4-3.5	1-3.2	0.6-4.8	0.6-1.5	0.1-0.6	0.2-0.3	0	0.4-2.7
United States	34.9-58.5	19.1-28.6	3.2-25.5	0.7-22.4	0.9-2.9	0.5-4.8	0.1-2.1	1-1.6	0.2-1.8	0.1-1.3	na	0.2-20.5
Minimum	20.0	1.0	1.0	0.1	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0
Maximum	80.0	55.0	44.7	52.0	4.7	11.0	15.0	3.7	7.3	3.9	0.5	32.8

Note :nd = not detected ; na = unavailable

The reaction of fly ash is affected by the mineralogy composition and the characteristics of the particle. Fly ash is a pozzolan material which has little or no cementitious properties. But, pozzolan can develop the cementitious properties with hydroxide calcium and water.[13]

d. Standard of Fly Ash

The following standard guidelines for fly ash are as follows:[14]

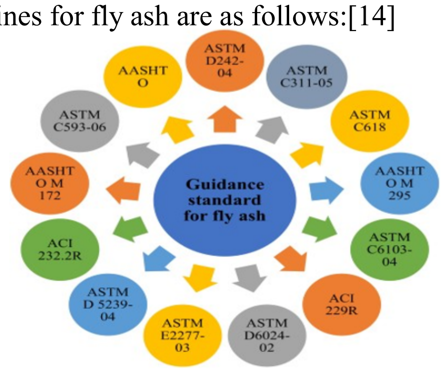

Figure 1. Standard guidelines of fly ash quality

e. Consistence

The consistence of fly ash, as a replacement of cement, needs more water than cement. The usage of fly ash as additional cement increases the binder consistency due to the increased volume of fine aggregate in the mixture. The values of the consistence vary. In this case fly ash doesn't need loots of water.[15]

f. Setting time

It is concluded in this research that with increasing fineness of fly ash, setting time of fly ash cement decreases, the beginning setting time varies from 20 minutes to 260 minutes, while the final setting time varies from 60 to 315 minutes, depends on the type and the quantity of fly ash. Due to high sulfate content on the surface of class C fly ash particle, the setting time is longer than class F fly ash.[12] here the Figure 2. The using of fly ash especially at high cement replacement rates can cause a very significant delay in setting time from the beginning to end.[16]

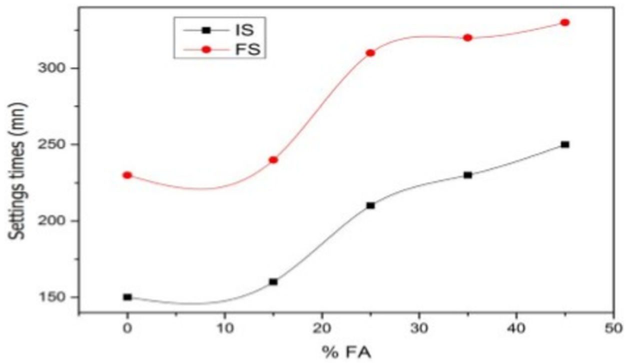

Figure 2. Fly Ash Mix Setting and The Effect on Setting Time

g. Workability

In this study, the enhancement of fly ash usage based on cement mass, increases the workability of mortar mixture and reduces the need of Portland cement.[17] Class C and F fly ashes with high aluminosilicate, and the fine grain size contributes to the enhancement of concrete workability.[13]

2. METHODS

This article aims to answer the question about how to use fly ash from time to time by doing review of literature studies. The following steps in writing this article are : planning the review about fly ash. Next step is by doing review about classification, characteristics, standard, consistency, setting times, and workability of fly ash. The last step is reporting the result about how to use fly ash for construction.

3. RESULTS AND DISCUSSION

3.1. The Use of Fly Ash

It can be concluded in this study that there are some reasons to use fly ash, they are:[7]
1. Minimalize the cost of fly ash disposal.
2. The less of land provision to dispose fly ash.
3. There is a financial benefit, compensation in processing and disposal costs.
4. Fly ash can replace some rare and expensive natural resources.

Fly ash has good performance and it is environmentally friendly, fly ash based construction material has a great potential as an alternative to substitute Portland cement to create the advantage of using fly ash in the world of construction.[2]. Based on study in Figure 3. The percentage of potential in using fly ash , production, and the usage of fly ash around the world are as follows:[18]

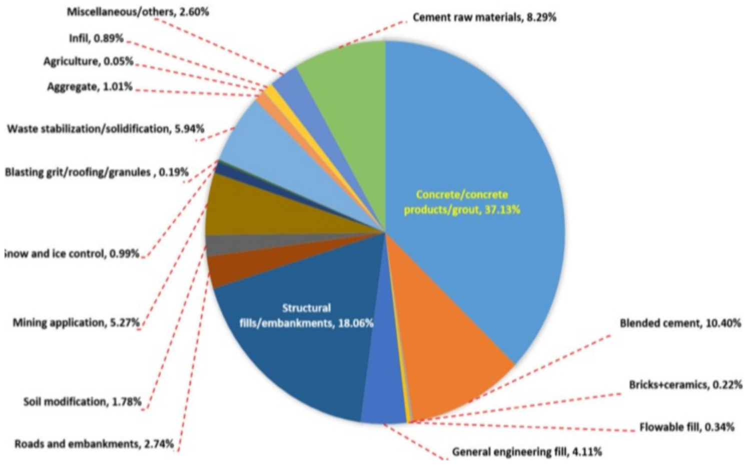

Figure 3. The percentage of potential in using fly ash , production, and the usage of fly ash around the world are as follows[18]

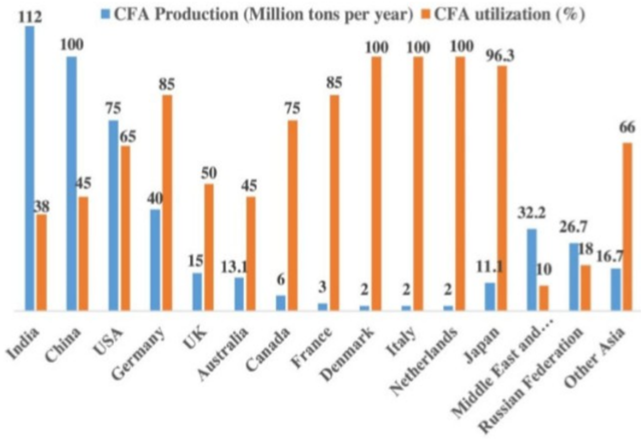

Figure 4. Production and fly ash utilization around the world. [18]

3.2. Fly Ash Utilization in Construction Industry

Fly ash can be used as raw material in various of construction industry because it contains oxide. Fly ash can be used for bricks production, ceramics production, road construction, concrete production and others.[19]. As seen in Figure 5.

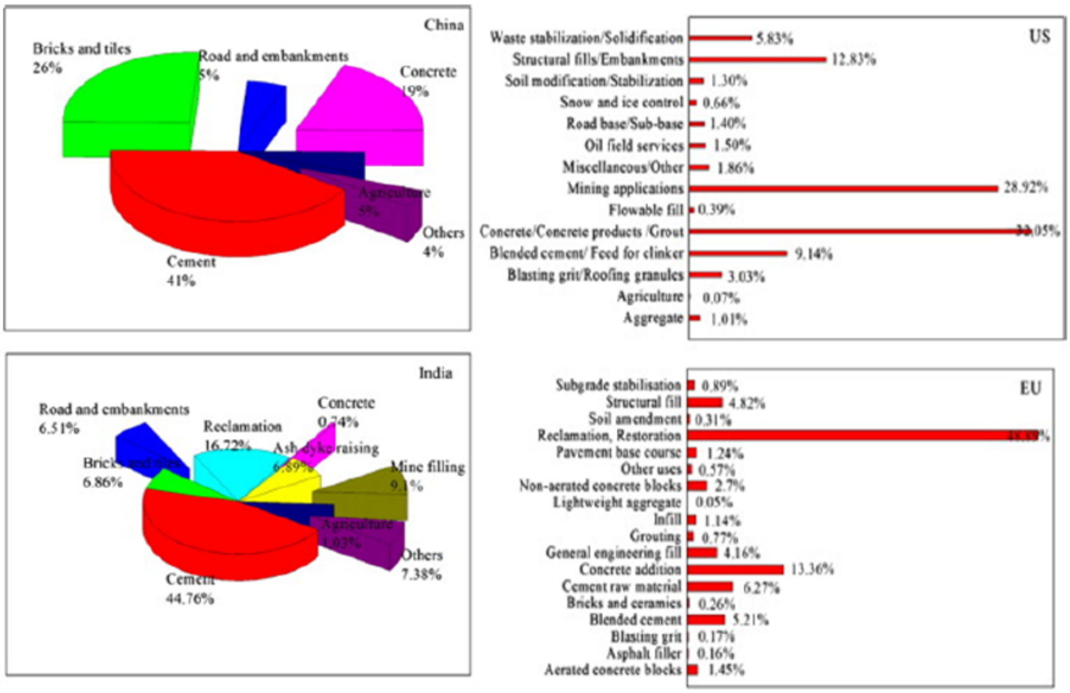

Figure 5. The utilization of Fly Ash in China, India, USA and EU

Partial replacement of cement with fly ash can reduce the needs of water, increase the workability of concrete, and reduce the concrete production costs and greenhouse gas emissions during cement production process.[5] the use of fly ash as the binder can increase the workability and reduce the possibility of bleeding to occur. Partial replacement of cement with class F fly ash can reduce the possibility of hydration heat to happen which is at risk of cracking in concrete.[20] the utilizationof fly ash in construction industry is not only to replace cement, but also to replace fine aggregate. In an experimental study conducted by Siddique, the effect of class F fly ash as a substitute for fine aggregate on filling performance. Fine aggregate (sands) with five percentages 10%, 20%. 30%, 40%, and 50% by weights. Tests of compressive strength, tensile strength, flexural strength, and modulus of elasticity were carried out at the ages of 7, 14, 28, 56, 91 and 365 days. The results of the tests shows the significance of enhancement in strength properties of plain concrete with the inclusion of fly ash as the partial replacement of fine aggregate (sands), and can be used effectivelyin structural concrete.

The other thing that is done bi Siddique , the replacement of fine aggregate with class F fly ash as much 10%, 20%, 30%, and 40%. The compressive strength tested at the age of 28 days gains for about 26 Mpa. The compressive strength test and abrasion conducted until 365 days. The result of the test shows that the abrasion resistance and compressive strength increase along with the increasing of the replacement of fine aggregate with fly ash percentage.[21] Experimental study that is done to investigate the effect of fly ash as a substitute of fine aggregate on filling performance. The effect of fly ash on the gradation distribution and compactness of the dry mixture is tested. Slump, bleeding, unconfined compressive strength (UCS), on a mixture of flyash and cement tested for fly ash content different cement- sand ratio. The result of the research shows that fly ash as fine aggregate can effectively increase mix gradation performance. Strength in a short time (3 days/ 7 days) increases with fly ash.

Meanwhile, strength and slump aged 28 days increased and then decreased, reaching maximum values of 8.58 MPa and 27.4 cm respectively at 30% fly ash content. At 5.2% fly ash content there was a decrease in bleeding. When the cement- sand ratio increased from 1:6 -1:4 the slump decreased by 27.5 cm and the bleeding rate decreased to 4.05%. However the mechanical properties significantly increase with the presence of cement content.[22]

3.3. Case Studies

Table.2. Case Studies FA [12]

No	Project	Place and country	Completion year	Project details	Fa used	Benefit of FA admixed concrete/remaks
1	1144 fifteenth street	Denver, Colorado, US	2018	42-story,603-foot high building, 640,00sq.feet office space	40%	a. Reduced the heat of hydration in miass concrete with a volume of about 1800 m^3 b. Slowed the initial curing process c. Preserved the strength and quality of concrete d. Minimised the cement and concrete required for the foundation e. Reduced the overall cost while increasing the strength
2	Apogee stadium	Denton, Texas. U.S	2011	University of North Texas stadium	35%	a. A carbon offset equivalent to the stadium's electricity production for three years was achieved. b. Obtained the highest level of LEED certification awarded by the U.S. Green Building Council.
3.	BAPS Hindu Mandir	Abu Dhabi, UAE	2022	BAPS Shri Swaminarayan mandir 3000-cubic meter concrete in foundation mat	55%	a. FA admixed concrete to construct the foundation mat to uphold the temple's heavy masonry b. Single placement of 3000 m3, one of the largest ever single concrete placements in UAE c. Reduced heat of hydration d. Minimised the thermal crack
4.	Burj Khalifa	Dubai, UAE	2010	163 floors concrete multi-use tower, 2717 feet height, 465,000 square foot building	25% FA and 7% SF for pile 40% FA for the raft	a. Reduced peak temperatures and the likelihood of cracking during mass placements in the arid climate. b. FA admixed high-performance concrete used for the construction as the substructure sits in an extremely corrosive environment with high chloride and sulfate concentration of 4.5 and 0.6%, respectively

5.	Calgary International airport runway and tunnel	Calgary, Alberta, Canada	2014	Airport runway and concrete traffic tunnel under the new runway	15%	a. Life cycle cost and the durability of the structure were the major consideration for the design of a structure with 400,000 m^3 of concrete
6.	Capital/Bank of America tower	Houston, Texas,U.S.	2019	The 35-story tower, 750,000 square feet of office	55%	a.The addition of FA resulted in a 33% reduction in the production of ozone depleting compound b. 19% reduction in global warning potential c. 12% reduction in acidification d. Saved one million pounds of CO_2 e.High Fa dosage reduced the heat of hydration f. Minimized the thermal cracks
7.	DFW connector	Dallas, Texas, U.S	2014	4 highways, 2 major interchanges, and 5 intersection bridges	25% (Class F FA)	a. FA admixed concrete used for temperature control,workability improvement, and to mitigate ASR and sulfate attack.
8.	Dover Air Force Base Runway Project	Dover, Delaware, U.S.	2016	US air force runway	Thermally refined class F FA	a. A renovation work to extend life span an additional 50 to 75 years
9.	Gautrain	Gauteng, South Africa	2012	50-mile-long, a high-speed commuter rail line	30 – 35 %	a. 28 million cubic feet of concrete with a life expectancy of 100 years b. Reduce the cost of construction, environmentally friendly, and higher strength than pure cement mix. c. Compressive strength exceeded 27.6 MPa within 24 hours and averaged 73.8 MPa after 28 days d. In foundation, FA is used with bentonite to provide good pumpability
10.	Global Change Institute Building	Brisbane, Australia	2013	GIC headquarters is a four-story building comprising three suspended concrete floors made from 33 precast geopolymer concrete panels	Geopolymer concrete (Class F FA and GGBS, no cement)	a. Emissions reductions of 80-90% b. 30% higher flexural strength c. High sulfate, acid, and chloride ion ingress resistance d. Low shrinkage e. Low heat of hydration

11.	Georgia Port Authority Mobile Gantry Crane Runway	Savannah, Georgia	2012	In 2012, the Georgia Port Authority undertook reconstruction of a failing portion of the concrete runways which are subjected to 56 tonnes	Class C FA	a. Class C fly ash to help improved the performance characteristics of concrete over many traditional cement concretes b. Improved volume stability, corrosion resistance, scaling and sulfate resistance, and immunity to ASR c. Less heat of hydration d. Minimized thermal cracking
12.	Hoover Dam Bypass	Mohave County, Arizona, U.S.	2010	Concrete arch bridge	20% (Class F FA)	a. Very low w/c ratio of 0.31 b. Achieved 28 Mpa in one day and 83 MPa in 56 days c. Low heat of hydration
13.	I-35W Saint Anthony Falls Bridge	Minneapolis, Minnesota, U.S.	2008	Concrete bridge,Footings, drilled shafts, piers and superstructure	Superstructure- 25% FA Footing and drilled shaft- 18% FA Piers- 16%FA	a. Designed for a 100-year life b. 3800 m3 concrete c. High strength d. Frost resistance
14	J. Craig Venter Institute	La Jolla, California, U.S.	2013	Three-story, 45,000-square foot laboratory facility	30%	a.Environmentally sustainable concrete b. Aesthetic quality c. LEED platinum standards
15.	Medupi Power Station	Lephalale, South Africa	2020			a.Temperature control in mass concrete placement b.Met specific shrinkage standards c. Less permeable concrete d.Dense structure e. Resisting abrasion and chemical ingress
16.	Niagara Region Wind Farm	Niagara, Ontario, Canada	2016	Concrete towers for 77 wind turbines spread out over a 170-square-mile area in south-east Ontario. Collectively, the turbines, each 425 feet high, utilized 2.6 million cubic feet of ready-mix concrete and 1.3 million cubic feet of precast concrete	50%	a. Low heat of hydration b. Temperature control c. High strength d. Low mixture cost e. Thermal cracking

17	Oroville Dam Spillway Recovery	Oroville, Butte County, California, U.S.	Phase 1: 2018	Earth-filled embankment dam on the Feather River near Oroville	50% Class F FA	a. Low heat of hydration b. Less thermal cracking
18	Saluda Dam	Columbia, South Carolina, U.S.	2005	Roller compacted concrete (RCC) gravity dam downstream of the dam.	50%	a. Improved workability b. Reduce heat of hydration
19	San Francisco-Oakland Bay Bridge Eastern Span	Oakland, California, U.S.	2013	San Francisco-Oakland Bay Bridge of 4.5 miles	Footings- 50% FA Columns- 40% FA	a. Improved workability b. Reduce heat of hydration c. improved workability d. Reduced heat of hydration e. Reduced thermal crack f. Mitigated ASR g. Improved corrosion resistance h. 150 years of service life
20	Transbay Block 9 Residential Tower	San Francisco, California, U.S.	2019	42-story residential tower	40%	a. Environmentally sustainable concrete b. Improved workability
21	University of Minnesota Recreation Center Expansion	Minnesota, U.S.	2013	HVFA concrete was used extensively to strengthen the structural elements of the remodelled facility of UMN's recreation centre as well as for its aesthetic appeal as an exposed material	30%	a. Enhanced workability b. High strength c. Enhanced durability d. Lower cost
22	Philadelphia Hotel	Philadelphia, Pennsylvania	2018	Nine-foot-thick foundation covered 20,000 square feet and contained 25.2 million pounds of concrete.	50%	a.Slowed down the hydration process thus reduced generation oh heat at the core concrete

4. CONCLUSION

Based on the result of the analysis and discussion above, it can be concluded that:

1. Fly ash based construction material has a great potential alternative to Portland cement, because of the good performance and environmentally friendly, while the usage of fly ash in high amount of volume, as replacement of fine aggregate helps in minimalizing the depletion of mineral resource.
2. Fly ashes classification are F class, A low calsium fly ash under 10 %, usually comes from high

level of bituminous coal and anthracite. This kind of fly ash is pozzolanic. While C class stands for a high calsium fly ash above 10 % that is usually made of burning low rank lignite and subbituminous coal and this fly coal has the properties of cement.

3. Fly ash standards are ASTM D242-04, ASTM C311-05, ACI 229 R, ASTM D6024-02, ASTM E 2277-03, ASTM D 5239-04, AC 232.2 R, ASSHT O M 172, ASTM C393-06, AASHT O. Consistency of fly ash as cement substitute needs more water, while fly ash as the additional mixture of cement needs few of water and increasing the binder consistency. The use of fly ash with a high cement replacement rate can result in a delay in setting time.
4. Fly ash can be used as raw material for construction industry because it is a material that contains oxide. Fly ash can be used for bricks production, ceramics production, road construction, concrete production and etc.
5. The purposes of fly ash utilization are to minimalize the disposal costs of fly ash, provide less area for fly ash disposal, provide financial benefit, compensate processing and disposal costs, replace some rare and expensive resources, have good performance and envirinmentally friendly.
6. The result of the test shows a significant enhancement in the properties of plain concrete by adding class F fly ash as partial replacement for some fine aggregate (sands), and can be used effectively in structural concrete. Compressive strength is tested at the age of 28 days and resulted 26 Mpa. Compressive strength and abrasion test is being done for 365 days. The result of the tests show that the endurance for compressive strength and abrasion increase along with the increase of replacing fine aggregate with fly ash percentage.

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