



# **Experimental Investigation on Nano-Silica Modified High Volume Fly Ash Concrete under Elevated Temperature Exposure**

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**ABSTRACT:** Waste disposal is a big problem that many countries around the world are dealing with. Fly ash is a type of waste that comes from burning coal in power plants. Because there is less availability of raw materials and because protecting the environment from pollution is very important, there is a growing need to develop new building materials from industrial waste like fly ash. This waste is causing serious disposal issues because it can harm the environment. Pozzolanic concrete is widely used in many parts of the world, especially in industries like oil, gas, nuclear, and power.

Its use is increasing because of how strong and durable it is, how good it is for the environment, and how it helps save energy. However, these types of concrete are often exposed to very high temperatures for long periods in these industries. Even though concrete is thought to be fire-resistant, it can still suffer a lot of damage or even break completely when exposed to high temperatures. At such high temperatures, the chemical changes in the material weaken the structure, which reduces the strength of fly ash concrete. Fly ash is used as a supplement in concrete to improve its strength and durability. It can be added as an ingredient, used to partially replace cement, or used in place of fine sand. It can also be used as a full replacement for fine sand or as an extra ingredient to change the properties of concrete. In this study, the strength, tensile strength, and elasticity of fly ash concrete were tested at temperatures up to 120°C. The mix used was in the ratio 1:1.45:2.2:1.103, with a water-cement ratio of 0.5 by weight. Cement was replaced with 30%, 40%, and 50% fly ash by weight. Tests were done for compressive strength, split tensile strength, and modulus of elasticity. These tests were conducted at room temperature, 80°C, 100°C, and 120°C for all types of fly ash concrete at two different curing times, 28 and 56 days. A reference concrete without any fly ash was also tested. The test results showed that concrete with up to 30% fly ash replacement had strength similar to the reference concrete without fly ash. For mixes with 30%, 40%, and 50% fly ash replacement, the strength was lower than the control mix at all ages, but the strength of all mixes kept increasing over time. As the temperature increased, the compressive strength of the mixes with 30%, 40%, and 50% fly ash replacement decreased by 11.4%, 30.1%, 28.9%, and 27.5%, respectively, at 120°C compared to room temperature.

**KEYWORDS:** Fly Ash Concrete, Pozzolanic Concrete, High Temperature, Compressive Strength, Split Tensile Strength, Modulus of Elasticity, Cement Replacement.

## **I. INTRODUCTION**

Concrete containing pozzolanic materials such as fly ash is widely used in modern construction, especially in oil, gas, nuclear, and power industries due to its improved strength, durability, and environmental benefits. Fly ash, a by-product of coal combustion in thermal power plants, is commonly used as a supplementary cementitious material in concrete. Its utilization not only reduces the consumption of Portland cement but also helps in managing industrial waste and lowering environmental pollution.

In many industrial structures, concrete may be exposed to elevated temperatures for long periods. Although concrete is generally considered fire-resistant, exposure to high temperatures can significantly affect its mechanical and physical properties. At elevated temperatures, dehydration of hydration products, decomposition of calcium hydroxide, and

changes in the microstructure lead to loss of strength and stiffness. Thermal stresses, pore pressure development, and incompatibility between cement paste and aggregates can further contribute to cracking and spalling of concrete.

Fly ash plays an important role in improving the performance of concrete by enhancing workability, reducing water demand, decreasing heat of hydration, and improving long-term strength and durability. High-volume fly ash concrete can also reduce drying shrinkage and thermal cracking, making it suitable for mass concrete structures. The pozzolanic reaction between fly ash and calcium hydroxide produces additional cementitious compounds, which refine the pore structure and improve the overall durability of concrete.

Despite these advantages, the behavior of fly ash concrete under elevated temperature conditions requires further investigation. High temperatures may alter the microstructure of concrete, affecting its mechanical properties such as compressive strength, tensile strength, and modulus of elasticity. Therefore, understanding the performance of fly ash concrete at elevated temperatures is essential for the safe design and assessment of concrete structures exposed to fire or high-temperature environments.

## II. LITERATURE SURVEY

Arunkumar Cheng et al. [1] looked into how high temperatures affect the strength and how concrete behaves under stress and strain in high strength concrete (HSC). They tested stress-strain curves at several temperatures (20, 100, 200, 400, 600, and 800°C) for four types of HSC. The results showed that plain HSC becomes brittle at temperatures below 600°C but becomes more ductile above that temperature. HSC with steel fibers starts showing ductility at temperatures over 400°C. The compressive strength of HSC drops by about a quarter of its original strength when the temperature is between 100 and 400°C. Strength continues to decrease with higher temperatures and drops to about a quarter of its initial strength at 800°C. The strain at peak loading also increases with temperature, going from 0.003 at room temperature to 0.02 at 800°C.

Estakhri and Mohidekar [2] collected data from 18 power plants in Texas and found that 6.6 million tons of fly ash are made every year there, with about 2.7 million tons (or 40%) sold for use in concrete or other products.

Researchers estimated concrete production in Texas and suggested that replacing 60 percent of the portland cement used in concrete with fly ash could reduce carbon dioxide emissions by 6.6 million tons annually by 2015. Fly ash improves the workability of fresh concrete and reduces the heat released during the curing process. It also increases the strength, reduces permeability, and improves resistance to chemical damage in hardened concrete. Canadian research has led to the development of high volume fly ash (HVFA) concrete, where up to 60 percent of the Portland cement is replaced by Class F fly ash. HVFA concrete is strong, easy to work with, and has a low temperature rise during curing. One challenge for the industry is that it takes longer to set, which can actually be an advantage during a typical Texas summer.

Felicetti and Gambarova [3] discussed the use of high strength concretes (with compressive strength over 60MPa) in special structures that must function in high temperature environments or withstand severe thermal accidents. They studied the residual mechanical properties of two high strength concretes (with compressive strengths of 72 and 95MPa) using siliceous aggregates, mainly flint, after being subjected to uniaxial compression following a single thermal cycle at 105, 250, 400, and 500°C. Both concretes are sensitive to high temperatures. Even though they have good mechanical properties at room temperature (over 70MPa), even with lean mix and a relatively high water/binder ratio, their strength and stiffness drop greatly at and above 250°C. After a cycle at 250°C, their residual strength drops to between 66 and 80 percent of the original strength. The decrease in Young's modulus is even more noticeable. Both concretes are brittle below 250°C, but as the temperature increases, the material becomes softer. However, the simultaneous decrease in both compressive strength and Young's modulus means that toughness does not improve significantly below 250°C, but it increases a lot beyond 400°C. The failure in the cylinders is marked by splitting through both the mortar and the aggregate particles, with no shear bands forming. Below 250°C, only a few splitting cracks form just before or at the peak stress, but above 250°C, more and thinner cracks appear, and the fracture process becomes more irregular due to prior thermal fracturing.

Fu et al. [4] developed a 2-D mesoscopic thermoelastic damage model to study how thermal stress fields and associated fractures behave in cement-based composites with multiple circular or irregular inclusions exposed to high

temperatures. They found that thermal stress fields and cracking are mainly influenced by three factors: (i) the difference in thermal expansion between the matrix and the inclusions, (ii) how the inclusions are arranged, and (iii) the heterogeneity and shape of the inclusions. Thermal cracks first appear between two inclusions that are close together or have sharp corners when the thermal expansion coefficient of the inclusions is higher than that of the matrix. The spread of cracks in the matrix stops when an inclusion with higher strength is at the tip of the crack. These numerical findings were also used to examine the thermal cracking history of concretes with different aggregate arrangements.

Ghosh and Nasser [5] reported on the impact of high temperatures (up to 232°C) and high pressures (up to 13.8 MPa) on the strength and elasticity of concrete with a compressive strength of 50 to 70 MPa that contains lignite fly ash and a fixed amount of condensed silica fume. They tested five different temperatures ranging from 21 to 232°C and three different pressures ranging from 5.2 to 13.8 MPa. The strength and static modulus of elasticity decreased gradually as the temperature rose. A physical and chemical transformation of the paste occurred as temperature increased. At high temperatures, chemical changes in the gel weakened the bonding in the matrix, causing a loss of strength and elasticity in fly ash and silica fume concrete.

### III. EXPERIMENTAL DATA

Cement IS mark 43 grade cement (Brand-ACC cement) was used for all concrete mixes. The cement used was fresh and without any lumps. Testing of cement was done as per IS: 8112-1989 [26]. The cement used was similar to Type I cement (ASTM C 150). The various test results conducted on the concrete are reported in table:

**Table 3.1 Properties of cement**

S.No.	Characteristics	Values obtained	Standard value
1.	Normal consistency	34%	-
2.	Initial setting time (minutes)	48min.	Not less than 30
3.	Final setting time (minutes)	240 min.	Not greater than 600
4.	Fineness (%)	3.5%	<10
5.	Specific gravity	3.07	-

**Table 3.2 Properties of Coarse aggregates**

S.no.	Characteristics	Value
1.	Type	Crushed
2.	Maximum size	20mm
3.	Specific gravity (10mm)	2.704
4.	Specific gravity (20mm)	2.825
5.	Total water absorption (10mm)	1.6432%
6.	Total water absorption (20mm)	3.645%
7.	Moisture content (10mm)	0.806%
8.	Moisture content (20mm)	0.7049%
9.	Fineness modulus (10mm)	6.46
10.	Fineness modulus (20mm)	7.68

**Table 3.3 Sieve analysis of 10mm aggregates**

S.No.	Sieve No.	Mass Retained (kg)	percentage Retained, %	percentage Passing, %	Cumulative %age Retained
1.	80mm	-	0.00	100	0.00
2.	40mm	-	0.00	100	0.00
3.	20mm	-	0.00	100	0.00
4.	12.5 mm	0.555	18.5	81.5	18.5
5.	10mm	0.8905	29.68	51.82	48.18

6.	4.75 mm	0.9565	31.88	19.94	80.06
7.	Pan	0.5970	19.90	0.04	99.96
$\Sigma C =$					146.74

Fineness Modulus of Coarse aggregate (20mm) =  $\Sigma C + 500 / 100 = 268.244 + 500 / 100 = 7.68$

Table 3.5 Properties of fine aggregates

S.No.	Characteristics	Value
1.	Type	Uncrushed(natural)
2.	Specific gravity	2.68
3.	Total water absorption	1.02%
4.	Moisture content	0.16%
5.	Net water absorption	0.86%
6.	Fineness modulus	2.507
7.	Grading zone	III

Table 3.6 Sieve analysis of fine aggregate

S.No.	Sieve No.	Mass Retained (gms)	percentage Retained, %	percentage Passing, %	Cumulative %age Retained
1.	4.75 mm	95.0	9.5	90.5	9.5
2.	2.36 mm	42.5	4.25	86.25	13.75
3.	1.18 mm	110.5	11.05	75.2	24.8
4.	600 $\mu$ m	128.5	12.85	62.35	37.65
5.	300 $\mu$ m	308.0	30.8	31.55	68.45
6.	150 $\mu$ m	281.0	28.1	3.45	96.55
7.	Pan	34.5	3.45	-	
$\Sigma F =$					250.7

Fineness Modulus of fine aggregate =  $\Sigma F / 100 = 250.7 / 100 = 2.507$

Table 3.7 Chemical Composition of Fly Ash

S.N.	Particulars	Requirement ASTM C 618 (%)	Test Results (%)
1.	(SiO <sub>2</sub> +Al <sub>2</sub> O <sub>3</sub> +Fe <sub>2</sub> O <sub>3</sub> ), %	70.0 min	91.69
2.	SiO <sub>2</sub> , %	35.0 min	59.08
3.	MgO	5.0 max	0.36
4.	Sulphuric Anhydride, %	3.0 max	0.11
5.	Total Alkalies Na <sub>2</sub> O, %	1.5 max	0.62
6.	Total Loss on Ignition, %	5.00 max	2.08

Table 3.8 Physical Properties of Fly Ash

S.N.	Particulars	Requirement ASTM C 618	Test Results
1.	Fineness Specific Surface (cm <sup>2</sup> /gm)	3200 min	3258
2.	Residue on 45 micron (wet sieving)	34 max	30.17
3.	Lime Reactivity (kg/cm <sup>2</sup> )	45 min	51.03

4.	Compressive strength (kg/cm <sup>2</sup> ), 28 days	Not less than 80% of strength Of corresponding plain cement Mortar cubes	85.99
5.	Dry shrinkage, %	0.15 max	0.04
6.	Soundness expansion by autoclave, %	0.8 max	0.03

**Table 3.9 Mix Designation**

Grade of concrete	Concrete Type	Temperature, °C	Designation	Percentage bind ratio	
				Cement	Flyash
M-20	Control Mix	N*	M-0	100	0
	Fly ash concrete	80	M-1	100	0
		100	M-2	100	0
		120	M-3	100	0
		N	M-4	70	30
		80	M-5	70	30
		100	M-6	70	30
		120	M-7	70	30
		N	M-8	60	40
		80	M-9	60	40
		100	M-10	60	40
		120	M-11	60	40
		N	M-12	50	50
		80	M-13	50	50
		100	M-14	50	50
120		M-15	50	50	

where, N\* is the room temperature

**Table 3.10 Proportion of M-20 Grade Concrete**

	Cement kg/m <sup>3</sup>	Fine Agg. kg/m <sup>3</sup>	Course Agg. (10mm) kg/m <sup>3</sup>	Course Agg. (20mm) kg/m <sup>3</sup>	Fly Ash kg/m <sup>3</sup>	Water (lts/m <sup>3</sup> )	Plasticizer (lts/m <sup>3</sup> )	Temp., °C	Slump, mm
M-0	372	538.45	410.4	818.85	0	186	4.464	N	45
M-1	372	538.45	410.4	818.85	0	186	4.464	80	45
M-2	372	538.45	410.4	818.85	0	186	4.464	100	45
M-3	372	538.45	410.4	818.85	0	186	4.464	120	45
M-4	260.4	538.45	410.4	818.85	111.6	186	5.022	N	45
M-5	260.4	538.45	410.4	818.85	111.6	186	5.022	80	45
M-6	260.4	538.45	410.4	818.85	111.6	186	5.022	100	45
M-7	260.4	538.45	410.4	818.85	111.6	186	5.022	120	45
M-8	223.2	538.45	410.4	818.85	148.8	186	5.394	N	45
M-9	223.2	538.45	410.4	818.85	148.8	186	5.394	80	45
M-10	223.2	538.45	410.4	818.85	148.8	186	5.394	100	45
M-11	223.2	538.45	410.4	818.85	148.8	186	5.394	120	45
M-12	186	538.45	410.4	818.85	186	186	6.882	N	45
M-13	186	538.45	410.4	818.85	186	186	6.882	80	45
M-14	186	538.45	410.4	818.85	186	186	6.882	100	45
M-15	186	538.45	410.4	818.85	186	186	6.882	120	45

IV. EXPERIMENTAL RESULTS

Table4.1: Compressive Strength (MPa) of Fly Ash Concrete

Fly Ash Content, %	Temperature, °C	Designation	Compressive Strength, MPa	
			28days	56days
0	N	M-0	23.0	29.4
0	80	M-1	22.9	27.0
0	100	M-2	19.3	26.5
0	120	M-3	17.6	26.0
30	N	M-4	16.2	25.2
30	80	M-5	13.3	20.5
30	100	M-6	12.1	19.7
30	120	M-7	10.8	17.6
40	N	M-8	15.4	20.4
40	80	M-9	14.3	17.9
40	100	M-10	12.9	17.8
40	120	M-11	12.8	14.5
50	N	M-12	10.8	13.3
50	80	M-13	10.5	12.2
50	100	M-14	8.9	11.3
50	120	M-15	8.4	9.6

Table4.2: Split tensile strength (MPa) of Fly Ash Concrete

Fly Ash Content, %	Temperature, °C	Designation	Split tensile strength, MPa	
			28 days	56 days
0	N	M-0	2.8	3.0
0	80	M-1	2.0	2.8
0	100	M-2	1.9	2.5
0	120	M-3	1.6	2.4
30	N	M-4	1.7	2.7
30	80	M-5	1.4	2.3
30	100	M-6	1.3	2.2
30	120	M-7	1.2	2.0
40	N	M-8	1.4	2.1
40	80	M-9	1.1	1.6
40	100	M-10	1.0	1.5
40	120	M-11	0.7	1.3
50	N	M-12	0.7	1.4
50	80	M-13	0.6	1.1
50	100	M-14	0.5	0.9
50	120	M-15	0.3	0.7

Table4.3: Modulus of elasticity (GPa) of Fly Ash Concrete

Fly Ash Content, %	Temperature, °C	Designation	Modulus of Elasticity, GPa	
			28days	56days
0	N	M-0	17.6	26.2
0	80	M-1	15.1	21.3
0	100	M-2	14.7	17.8

0	120	M-3	11.6	16.4
30	N	M-4	10.9	19.4
30	80	M-5	9.6	16.3
30	100	M-6	9.5	16.2
30	120	M-7	9.9	15.8
40	N	M-8	7.7	15.8
40	80	M-9	6.9	15.4
40	100	M-10	6.1	15.3
40	120	M-11	5.1	15.2
50	N	M-12	5.9	8.5
50	80	M-13	5.7	7.9
50	100	M-14	4.8	7.7
50	120	M-15	4.4	7.6

## V. CONCLUSION

Experiments The following conclusions were drawn from this study:

1. The compressive strength of concrete went down as more cement was replaced with Class-F fly ash. However, at every level of cement replacement, the strength increased as the concrete aged.
2. Changes in temperature affected the compressive strength. As the temperature rose from room temperature to 120°C, the compressive strength went down.
3. Both splitting tensile strength and modulus of elasticity increased with age at each level of cement replacement with fly ash up to 50%. However, as the amount of fly ash increased, these properties decreased.
4. Increasing the temperature up to 120°C reduced the splitting tensile strength and modulus of elasticity. This happened because the chemical changes in the gel weakened the bonding in the matrix, leading to a loss of strength in the fly ash concrete at high temperatures.
5. The specimens failed after forming several vertical cracks along the loading direction, and there were no failures of the shear type.

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