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Structural Characteristics of High Volume Fly Ash Concrete Subjected to Elevated Temperature

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Abstract: Fly ash is a mineral additive that is added to concrete to increase the material's strength and longevity. Fly-ash concrete lost its strength because of the chemical shift in the gel brought on by the high temperatures. The matrix bonding weakened as a result, which resulted in the loss of strength. Fly ash may be used in concrete in a variety of ways, including as an additive, a partial replacement for cement, a full or partial replacement for fine aggregates, or as an extra component that contributes to the development of a variety of various properties. The electricity, nuclear, andoil and gas industries are just a few of the many global businesses that often employ pozzolanic concrete. Additionally, pozzolanic concrete is used to build tunnels and bridges. These concrete slabs have been exposed to the elements for a long time, which has caused high temperatures to be created inside of them in addition to the usual danger of fire. Even though it is well known that concrete is a substance that does not readily catch fire, concrete that is exposed to very high temperatures nevertheless can sustain significant harm, including a full and total collapse. The compressive strength, split tensile strength, and modulus elasticity of fly ash concrete were examined at temperatures as high as 120 degrees Celsius. In the experiment, a mix ratio of 1:1.45:2.2:1.103 and a water-cement ratio of 0.5 by weight were used. Fly ash was used as a substitute for cement in a variety of ways throughout this experiment. The elastic modulus of the material, as well as its split tensile strength and compressive strength, were also studied. The replacement ratios were 30, 40, and 50%, depending on the quantity of cement utilized. The compressive strength, split tensile strength, and elastic modulus of each kind of fly-ash concrete were evaluated at a variety of temperatures and after a certain length of curing time (between 28 and 56 days). The test findings showed that the elastic modulus, compressive strength, and split tensile strength of concrete with up to 30% cement replacement were equivalent to those of reference concrete without fly ash. The performance of the control mixture was superior to that of concrete mixes that incorporated 30, 40, or 50% fly ash in lieu of cement in terms of compressive strength, split tensile strength, and elastic modulus. Regardless of how long ago the pairings were created,this was always the case. On the other side, a combination's efficacy will improve with time. The compressive strength of concrete mixes containing 30, 40, or 50% fly ash instead of cement is decreased by 11.4%, 30.1%, 28.9%, and 27.5%, respectively, at a temperature of 120 degrees Celsius when compared to concrete compositions without fly ash.

Keywords: Fly ash, Pozzolanic concrete, compressive strength, and split tensile strength, elastic modulus, temperatures

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1. Introduction

The nuclear and power-generating sectors, together with the oil and gas industries, are among the principal consumers of pozzolanic concretes, which find broad usage all over the globe. Pozzolanic concretes also find use in the oil and gas industries. Because of their better structural performance, environmental friendliness, and implications for energy conservation, these concretes are finding more and more uses on a daily basis.

This is since they are kind toward the environment. Even though it is widely acknowledged that concrete is an excellent material for fireproofing, hightemperatures have the potential to cause significant damage or even lead to the complete collapseof the structure.

This is the case even though it is generally acknowledged that concrete is an excellent material for fireproofing. These compounds have the potential to increase the durability of concrete as well as speed up the rate at which it builds strength over time. In addition to this, they have the capability of slowing down the rate at which heat is released, which is advantageous for mass concrete. It is well known that concrete undergoes transformations in its characteristics, most notably between the temperatures of 100 and 300 degrees Celsius. The mechanical properties of an object start to deteriorate as the temperature rises over 300 degrees Celsius. The way concrete responds when subjected to high temperatures is determined by a number of factors, some of which include the heating rate, the peak temperatures, the dehydration of the CSH gel, the phase transitions,and the thermal incompatibility between the aggregates and the cement paste. All of these factors come into play when the concrete is heated to a high level. On the other hand, doing non-destructive concrete quality assessments on buildings that have been exposed to fire or temperatures below freezing may be challenging. These types of structures may have lost some of their original integrity.The bulk of the organizations that are now in existence tend to use the age of 28 as a standard for membership eligibility.

2. Experimental Study

The major objective of the experiment was to ascertain the behavior of concrete when subjected to temperatures as high as 120 degrees Celsius and when the cement in the concrete was substituted with a significant quantity of fly ash. In this investigation, the major qualities that were investigated were the material's compressive strength, split tensile strength, and modulus of elasticity. Thecomponents that were utilized in the construction of the concrete samples, together with the results of the tests that were conducted on the samples,

2.1 Cement

All concrete combinations, including the cubes and cylinders used in the casting process, were made using cement from Ordinary Portland Cement (OPC) Grade 43, which is a high-quality Portland cement. A uniform shade of grey with a little greenish tinge pervaded the whole batch of cement, and there were no solid lumps in the mixture. It was put through its paces in compliance with Indian safety regulations and requirements (BIS-8112:1989). As previously indicated, the results of thetests are provided in Table 1, which summarizes the findings.

Table 1: Physical Properties of cement

Characteristics	**Values obtained**
Normal consistency	32%
Initial setting time (minutes)	58 min.
Final setting time (minutes)	260 min
Fineness (%)	3.5 %
Specific gravity	3.09

2.2 Coarse Aggregates

Coarse aggregates with a maximum size of between 10 and 20 millimeters were used in the operationthat was now taking place. These aggregates could be found in the region around the activity. The aggregates that had a size of 10 millimeters were sieved twice, the first time through a sieve that had a diameter of 10 millimeters and then a second time through a sieve that had a diameter of 4.75 millimeters. After that, the aggregates that were 0 millimeters in size were sieved through a sieve that had a size of. After that, they were washed to remove the dirt and dust, and then they were dried until the surface of each one was completely dry. The aggregates were inspected to ensure they met the requirements of the Indian Standard.

Table 2: Properties of Coarse Aggregates.

Characteristics	Value
Type	Crushed
Maximum size	20 mm
Specific gravity (10 mm) (20 mm)	2.714 2.841
Total water absorption (10 mm) (20 mm)	1.685 % 3.678 %
Moisture content (10 mm) (20 mm)	0.602 % 0.781 %
Fineness modulus (10 mm) (20 mm)	6.51 7.69

2.3 *Fine Aggregate*

The sand that was used in the trial program had been obtained from the surrounding region and was appropriate for use in reading zone III. After being strained through a sieve with a mesh sizeof 4.75 millimeters to remove any particles with a size greater than 4.75 millimeters, the sand was washed to remove any lingering dust. This was done in order to ensure that the sand was completelyfree of any impurities. The fine aggregates were put through their paces to make sure they met the requirements of the Indian Standard Specifications IS: 383-1970.

Table 3: Properties of fine aggregates.

Characteristics	Value
Type	Uncrushed (natural)
Specific gravity	2.78
Total water absorption	1.12 %
Moisture content	0.18 %
Net water absorption	0.76 %
Fineness modulus	2.511
zone	III

2.4 *Fly ash*

Several studies were conducted on the fly ash that was collected from the Thermal Power Plant in Panipat, which is in the state of Telangana. The ASTM C 311 standard requires that both the chemical and physical characteristics of it be investigated and assessed. The experiment's utilization of fly ash, including its chemical make-up as well as its physical properties and features.

Table 4: Physical Properties of Fly Ash.

Particulars	Test Results
Fineness Specific Surface (cm2/gm)	3264
Residue on 45 microns(wet sieving)	30.17
Lime Reactivity (kg/cm2)	51.03
Compressive strength(kg/cm2), 28 days	85.99
Dry shrinkage, %	0.04
Soundness expansion by auto clave, %	0.03

2.5 Fire exposure to specimens

An electric furnace that had been developed was used to heat the specimens to high levels. The electric furnace's greatest conceivable temperature of operation was 1000 degrees Celsius, and this temperature was used. Companions for the experiment included cubes of each concrete mix designed to withstand the heat and flames of a fire, as well as cubes of the remaining mix and HVFAmix. Three specimens of each set of concrete mix of OPC and HVFA were kept at the same increasedtemperatures of 100 o C, 2000 o C, 300 o C, 4000 o C, 500 o C, 6000 o C, 700 o C, and 8000 C. These temperatures ranged from 100 to 8000 degrees Celsius. The temperatures varied from very low to extremely high. One hour, two hours, and three hours pass while each temperature ismaintained in a constant condition for the corresponding amount of time. After this, the samples were placed out in the open so that the ambient air could bring the temperature down. After that, compression testing equipment (CTM) was used to put the cubes through an ultimate failure load test.

3. Results and Discussion

Temperature is one of the most important factors to consider when determining how strong something will be. A rise in temperature leads to a reduction in strength (both in compression and tension), as well as in stiffness (Young's modulus), in a material. Relationship between cause and effect The high temperatures caused a chemical reaction in the gel, which resulted in a weakeningof the matrix bonding. This, in turn, eventually led to a loss of strength in the fly ash concrete.

3.1 Compressive Strength

In this study, the values of strength properties for various fly ash components (0%, 30%, 40%, and 50%) are given at the end of various curing periods (28 days, 56 days). These fly ash components were able to incorporate different temperatures (40 °C, 80 °C, 100 °C, and 120 °C, respectively) at the conclusion of these curing periods. These values are based on the temperature at which the material was cured. These values are determined by the temperature at which the material was cured after it was manufactured. The temperature at which the material was cured after it was made is what establishes these values as the proper range for the variable. After each of the many healing periods has been carried out to its end, these figures are shown to you. These numbers have been presented after a number of different elapsed durations that have each lasted for a varying amountof time in total. In order to ensure that you get the most out of the experience possible, we have provided you with a summary of the findings of the study for your perusal. This is an example ofthe variety of compressive strengths that may be achieved by mixing several different cement replacements with one another at a number of various curing ages. In addition to this, this displays how the compressive strength of the material fluctuates in response to variations in both the quantity of fly ash that was employed and the temperature at which it was manufactured. The value of the compressive strength was found by rounding the result up to the next whole number after first taking the average of the results from three separate cylinder tests and then taking the average of those three results. As a result of this, it became possible to determine what the item's true worth really was. It is abundantly clear that the compressive strength of the concrete combinations that contained 30%, 40%, and 50% of fly ash as replacement level was lower than the compressive strength of the control mixture (M-0) at all ages and that the compressive strength of all mixtures continued to increase with the passage of time. On the other hand, it is plainly obvious that the control combination had a compressive strength that was lower than the compressive strength of the mixes that included fly ash at all ages. This was the case regardless of the age of the mixtures. On the other hand, the compressive strength of the concrete mixtures that included 30%, 40%, and 50% of flyash as a replacement for cement was lower than the compressive strength of the concrete mixturethat contained the control mixture (M). On the other hand, the compressive strength of the concrete blends that included 30%, 40%, and 50% of fly ash as a substitute for cement was lower than the strength of the concrete mixture that contained the standard control mixture. This finding was observed across all three percentages of fly ash inclusion (M). The results of this study were onlyjust published in an article that was distributed by the American Concrete Institute and have only been accessible for a short time now. The publication was named "Journal of the American Concrete Institute," and it was released not too long ago. As the temperature increased, there was a discernible decline in the compressive strength of concrete mixtures that had fly ash exchanged for cement in percentages of 30%, 40%, or 50%. This tendency was shown to be present at each of the three uniquepercentage levels. The quantity of fly ash that was added resulted in a reduction in the amount of compressive strength that was possessed by the material. This was the case each and every time, irrespective of the temperature outside. The rise in temperature, which was the direct cause of the occurrence, can be traced back to the reduction in the material's compressive strength, and this rise in temperature was the immediate cause of the phenomenon. Because of this, one might be forgiven for thinking that the material was becoming more fragile as more time passed.

Table 5: Compressive Strength (MPa)

Fly Ash Content, %	Temperature,°C	Designation	Compressive Strength, PA	
			28 days	56 days
FA-0%	N	MIX 0	23.89	29.49
FA-0%	80 °C	MIX 1	22.68	27.19
FA-0%	100 °C	MIX 2	19.99	26.64
FA-0%	120 °C	MIX 3	17.35	26.10
FA-30%	N	MIX 4	16.40	25.19
FA-30%	80 °C	MIX 5	13.25	20.49
FA-30%	100 °C	MIX 6	12.23	19.768
FA-30%	120 °C	MIX 7	10.61	17.52
FA-40%	N	MIX 8	15.89	20.39
FA-40%	80 °C	MIX 9	14.36	17.88
FA-40%	100 °C	MIX 10	12.99	17.71
FA-40%	120 °C	MIX 11	12.90	14.62
FA-50%	N	MIX 12	10.90	13.38
FA-50%	80 °C	MIX13	10.49	12.32
FA-50%	100 °C	MIX 14	8.89	11.15
FA-50%	120 °C	MIX 15	8.39	9.88

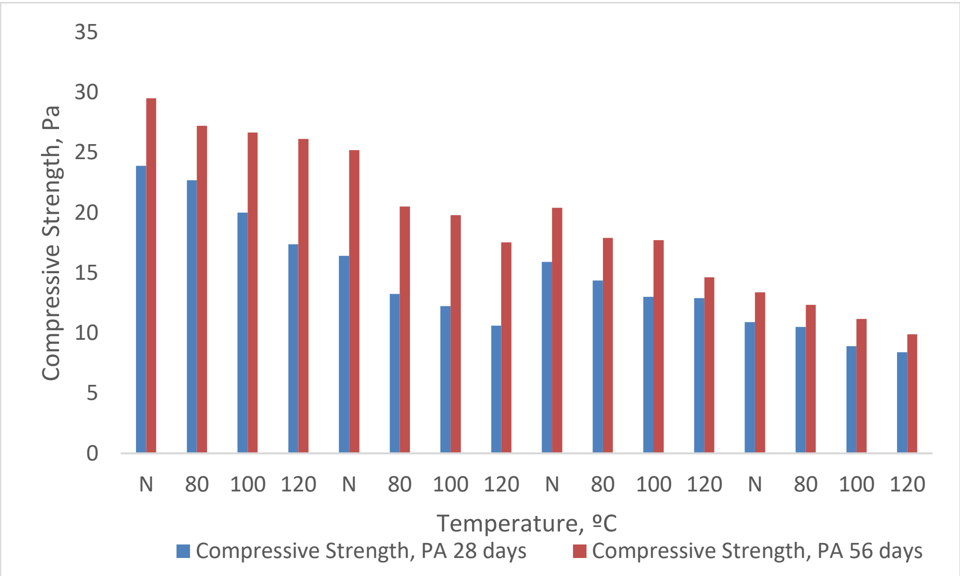

Figure 1: Compressive Strength (MPa) Compressive strength of Fly Ash concrete

3.1 *Split tensile strength*

The split tensile strength of Class F fly-ash traditional concrete was shown to be completely dependent on the air temperature as well as the amount of fly ash used in the mixture at various temperatures (with 30%, 40%, and 50% fly ash and a w/c of 0.5). No matter whether the combinationcomprised 30%, 40%, or 50% fly ash, this was the case. This phenomenon was observed, and it was shown that the split tensile strength of Class F fly cementitious materials at different temperatures depended on both the temperature and the amount of fly ash used. This conclusion was made feasibleby the fact that it really did happen, which is owing to the fact that Class F fly ash concrete's split tensile strength rose according to the amount of fly ash used in the mixture. This conclusion was drawn as a direct result of the information gathered from tests done on the concrete at various temperatures. These experiments were conducted over time. The values of and indicate the amount of variation in the split tensile strength. Similar to the connection between those two or more parameters and the effect it had on compressive strength, the relationship between the temperature and the quantity of fly ash in the material had an impact on splitting tensile strength. When comparedto those observed in the case of compressive strength, it was found that the variations in split tensile strength for replacements with Class F fly ash at various temperatures (40 degrees Celsius, 80 degrees Celsius, 100 degrees Celsius, and 120 degrees Celsius) were substantial. In particular, it was discovered that split tensile strength variations were substantially larger than those seen in the case of compressive strength. [An additional citation is required] This indicates that, across a rangeof temperatures, the quantity of fly ash and the split tensile strength are inversely related. This is evident when examining the findings of several different investigations. This was shown by the fact that the split tensile strength decreased as the temperature increased. The relationship's strength across a variety of temperature ranges is seen in the following graphic: There was an inverse link between the pace of temperature increase and the total amount of precipitation, with the temperatureincrease outpacing the precipitation.

Table 6: Split tensile strength

Fly Ash Content, %	**Temperature,°C**	**Designatio**	**Split tensile strengtMPA**	
			28 days	**56 days**
FA-0%	N	MIX 0	2.75	3.10
FA-0%	80 ºC	MIX 1	2.09	2.75
FA-0%	100 ºC	MIX 2	1.88	2.45
FA-0%	120 ºC	MIX 3	1.59	2.36
FA-30%	N	MIX 4	1.62	2.62
FA-30%	80 ºC	MIX 5	1.39	2.29
FA-30%	100 ºC	MIX 6	1.28	2.14
FA-30%	120 ºC	MIX 7	1.19	2.02
FA-40%	N	MIX 8	1.32	2.09
FA-40%	80 ºC	MIX 9	1.08	1.56
FA-40%	100 ºC	MIX 10	1.01	1.48
FA-40%	120 ºC	MIX 11	0.68	1.29
FA-50%	N	MIX 12	0.69	1.39
FA-50%	80 ºC	MIX13	0.59	1.07
FA-50%	100 ºC	MIX 14	0.61	0.85
FA-50%	120 ºC	MIX 15	0.28	0.65

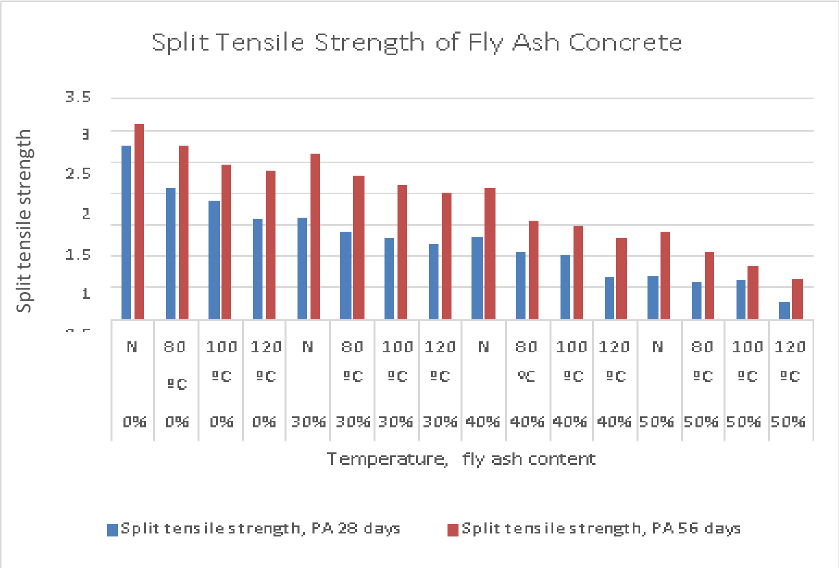

Figure 2: Split tensile strength

3.1 *Modulus of elasticity*

Calculating the slope of the chord that stretches from the origin to an arbitrary point on the stress- strain curve is how this inquiry determines the secant modulus, which is also known as the modulus of elasticity. This modulus may be found by looking at the stress-strain curve. This is the method that is used to calculate the modulus of elasticity. This step has to be completed before proceeding with the calculation of the secant modulus. Within the parameters of this particular experiment, the value of the secant modulus was found to correspond to one-third of the maximum stress. In orderto acquire an accurate result, the modulus of elasticity of concrete mixes was measured 28 and 56 days after they were mixed. This was done to get the most precise reading possible. Class F fly ash temperatures are 40 degrees Celsius, 80 degrees Celsius, 100 degrees Celsius, and 120 degrees Celsius. When contrasted with the modulus of the control mixture, the findings of the tests suggestedthat the modulus of concrete could possibly be reduced by using a significant quantity of fly ash asa component of the mixture. This was in comparison to the modulus of the mixture that served asthe control. The results of the testing unequivocally demonstrated that this is the case. The rate at which the temperature increased had a negative correlation with the quantity of precipitation thatwas received.

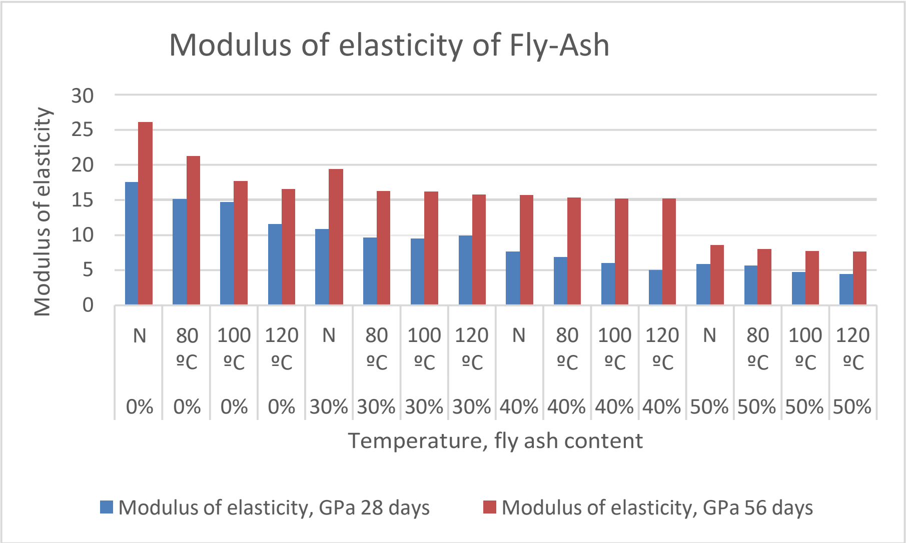

Figure 3: Modulus of Elasticity of Fly-Ash Concrete

4. Conclusions

- A decrease in the compressive strength of the concrete was found to have a direct correlation with the quantity of cement that was substituted with fly ash classified as Class F. On the other hand, regardless of the proportion of cement that was substituted with fly ash, therewas a general trend toward an increase in strength with increasing age across the board.
- Because of the many changes in temperature, the compressive strength saw several shifts. The compressive strength of the material decreased from room temperature to 120 degrees Celsius as the temperature increased.
- Also, the modulus of elasticity and the splitting tensile strength increased with age for each level of replacement of cement with fly ash up to 50%, but they both declined with higher volumes of fly ash. This was the case irrespective of the amount of cement that was substituted with fly ash. Despite the fact that the replacement value, which could have been either zero or fifty percent of the entire sum, was unknown, this was nonetheless the case.
- When the temperature was raised up to 120 degrees Celsius, a drop in splitting tensile strength as well as a decrease in the modulus of elasticity were noticed. When high temperatures were put on the fly ash concrete, its strength went down because the chemical changes to the gel made it harder for the matrix to stick together.
- Although there were no shear type failures that took place, the specimens failed in theloading direction after developing several longitudinal (vertical) fractures. However, thecommon type of failure did not take place.

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