# EFFECT OF MINERAL ADMIXTURES ON THE RESISTANCE OF CONCRETE SUBJECTED TO ELEVATED TEMPERATURES-A REVIEW

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**Abstract**

*Concrete is exposed to elevated temperatures during fire or when it is near to furnaces and reactors. The mechanical properties such as strength, modulus of elasticity and volume stability of concrete are significantly reduced during these exposures. When exposed to high temperature, the chemical composition and physical structure of the concrete change considerably. This may result in undesirable structural failures. Some of the mineral admixtures (pozzolanas) which are industrial wastes such as fly ash, silica fumes, GGBFS etc. may be used to enhance the resistance of concrete to high temperatures.*

***Keywords-- High Temperatures, Flyash, Admixtures, Chemical Composition, Concrete Change***

## I. INTRODUCTION

Ordinary portland cement is an ever demand, expensive and indispensable material in the construction industry. Currently in India, it is estimated that the annual consumption of cement concrete is to the tune of 400 metric tones. It is estimated that about one ton of carbon-di-oxide will be released into the atmosphere during the production of one ton of cement. This released carbon-di-oxide not only pollutes the air but also results in global warming. The concrete technologist and environmentalist are seriously thinking about the ways of reducing the environmental pollution and global warming caused due to production of cement. Therefore any steps which suggest the replacement of cement by some alternative eco friendly materials is a welcoming method both for concrete technologists as well as for environmentalists. Few decades' back it was found that some of the industrial wastes like fly ash, silica fume, blast furnace slag etc show some cementitious and pozzolanic properties when come in contact with moisture. These pozzolanic materials, to some extent replace the cement in the production of concrete. Fly ash is a by-product of the combustion of pulverized coal in thermal power plants. The fly ash which is an industrial waste in all the thermal power stations where coal is used for burning is causing various environmental problems.. The production of fly ash in India has crossed a mark of 110 million tones and only about 20% of this is utilized at present. Utilization of fly ash and silica fumes in concrete improve mechanical properties and also influence resistance of concrete which is consequence not only of the chemical nature of the hydrated cement paste but also of its microstructure. The durability of concrete structure is determined based on the parameters like strength properties, serviceability over a specified period of time. Concrete is possibly exposed to elevated temperatures during fire or when it is near to furnaces and reactors. The mechanical properties such as strength, modulus of elasticity and volume stability of concrete are significantly reduced during these exposures. This may result in undesirable structural failures. When exposed to high temperature, the chemical composition and physical structure of the concrete change considerably. To improve the strength properties the pozzolanic materials like fly ash and silica fumes are used. Fly ash and silica fumes are cheaply available hazardous wastes from thermal stations and silica industries, which improves the properties of concrete. These pozzolans when added enable the concrete to react with $Ca(OH)_2$to form additional calcium silicate hydrate which increases the density , fill the pores properly, refine the pore structure and the permeability which leads to the better durability . Fly ash concrete and silica fume concrete shows comparatively poor characteristics at premature ages, but its pozzolanic reaction improves with curing age and it also provides good resistance in aggressive media in concrete. Fly ash has become one of the primary constituents in blended cements because of its availability, its low cost, fineness and quality control. Fly ash, silica fumes are cheaply available, low in cost and hence can be used in concrete, which improves the strength properties and can be treated as good pozzolans. The improvements in combustion technology, usage of gas-fired boilers will lead to increased generation and availability of fly ash for future requirements in concrete industry. Fly ash and silica fumes act as best packing material hence reduces porosity and permeability. It is convenient to use fly ash pozzolanic mineral admixture to replace a large quantity of cement in concrete. It not only enhances the quality of concrete but it also helps in preservation of many resources as well as it is eco-friendly. Cement shows high compressive strength without fly ash in the early stages. But though initially the fly ash mixed concrete shows lower compressive strength values, but it increases with time later.

Concrete structures generally behave well in fires. Most fire-damaged concrete buildings can be repaired and put back to use even after severe fires. Certainly, the damaged structural members must be repaired to reach again the minimum strength, stiffness and ductility they ought to have had before the fires. When concrete is exposed to heat, chemical and physical reactions occur at elevated temperatures, such as loss of moisture, dehydration of cement paste and decomposition of aggregate. These changes will bring a breakdown in the structure of concrete, affecting its mechanical properties. Therefore, concrete members without visible damage may have reduced strength due to elevated temperatures. To evaluate and repair the fire-damaged concrete members, it is essential to understand the effect of temperature on the mechanical properties of concrete.

## II. LITERATURE REVIEW

**Chi-Sun Poon, Salman Azhar, Mike Anson, Yuk-Lung Wong** in their paper entitled **"Comparison of the strength and durability performance of normal-and high-strength pozzolanic concretes at elevated temperatures**", have studied the strength and durability performance of normal- and high-strength pozzolanic concretes incorporating silica fume, fly ash, and blast furnace slag at elevated temperatures up to 800$^{o}$C. The strength properties were determined using an unstressed residual compressive strength test, while durability was investigated by rapid chloride diffusion test, mercury intrusion porosimetry(MIP),and crack pattern observations . It was found that pozzolanic concretes containing fly ash and blast furnace slag give the best performance particularly at temperatures below 600$^{o}$C as compared to the pure cement concretes. Explosive spalling occurred in most high-strength concretes (HSCs) containing silica fume. A distributed network of fine cracks was observed in all fly ash and blast furnace slag concretes, but no spalling or splitting occurred. The high-strength pozzolanic concretes showed a severe loss in permeability-related durability than the compressive strength loss. Thirty percent replacement of cement by fly ash in HSC and 40% replacement of cement by blast furnace slag in normal-strength concrete (NSC) was found to be optimal to retain maximum strength and durability after high temperatures.

The author drew following conclusions:

- The pozzolanic concretes showed better performances at elevated temperatures than the pure OPC concretes except the mixes containing 10% CSF. This better performance was due to the reaction of this pozzolana with free lime, which enhances the strength and durability both at normal and high temperatures by reducing the free lime content.
- High temperatures can be divided into distinct ranges in terms of effect on concrete strength. In the range of 20-200$^{o}$C an increase in strength was observed in PFA and GGBS concretes. At 400$^{o}$C, most HSCs maintained their original strength while an average loss of 20% strength was observed in NSCs. After 400$^{o}$C, both types of concretes lost their strength rapidly and the rate of strength loss was more in HSC.
- In HSC the PFA concretes showed the best performance at elevated temperatures followed by GGBS, OPC and CSF concretes. The mix containing 30% PFA replacement gave the maximum relative residual strength. In NSC, the GGBS concretes gave the best performance followed by PFA and OPC concretes. The 40% replacement level was found to be the optimum.
- The mechanical strength of HSC decreased in a similar manner to that of NSC when subjected to high temperatures up to 800$^{o}$C. However, HSC maintained a greater proportion of its relative residual compressive strength than the NSC.
- The HSC suffered a marginally smaller loss of mechanical strength but a greater worsening of the permeability related durability than the NSC. Among HSCs the PFA concretes suffered the least damage in impermeability followed by GGBS, and CSF concretes. In NSC, the sequence was GGBS, PFA and OPC concretes.
- The surface crack pattern gave good indication about the internal pore structure of the concrete as shown by major cracks in CSF concretes and fine distributed cracks in PFA or GGBS concretes. More surface cracking was observed in HSC than NSC.
- Severe deterioration and spalling was observed CSF concretes and some HS-OPC concretes. Most of the spalling occurred between 400$^{o}$C and 600$^{o}$C. No spalling was observed in PFA or GGBS concrete.
- Conclusively, the PFA and GGBS concretes were found to be able to retain their properties better at elevated temperatures and can be used in those places where there is a high risk of fire. The CSF concrete with more than 5% replacement should be used at such places due to high risk of explosive spalling[1].

**BaharDemirel,OguzhanKelestemur** in their paper entitled **"Effect of elevated temperature on the mechanical properties of concrete produced with finely ground pumice and silica fume"**have studied the effect of elevated temperature on the mechanical and physical properties of concrete specimens obtained by substituting cement with finely ground pumice (FGP) at percentages of 5%, 10%, 15% and 20% by weight. To determine the effect of silica fume (SF) additive on the mechanical and physical properties of concrete containing FGP, SF has been added to all series except for the control specimen, which contained 10% cement by weight instead. The specimens were heated in an electric furnace up to 400, 600, and 800 degree C and kept at this temperature for one hour. After the specimens were cooled in the furnace, ultrasonic pulse velocity (UPC), compressive strength and weight loose values were determined. The results demonstrated that adding the mineral admixtures to concrete decreased both unit weight and compressive strength. Additionally, elevating the temperature above 600 degree C affected the compressive strength such that the weight loss of concrete was more pronounced for concrete mixture containing both FGP and SF [2].

**Kalifa Pierre, CheneGregoire, Christophe Galle**in their paper entitled **"High-temperature behavior of HPC with polypropylene fibres from spalling to microstructure",** are of the opinion that the addition of polypropylene (PP) fibres to high-performance concrete (HPC) is one way to avoid spalling of concrete under fire conditions. The present work contributes both to the understanding of the way in which fibres act and to optimizing the fibre dosage. Pore pressure measurements performed on heated specimens showed that the presence of fibres led to a large decrease in the extent of the pressure fields that build up in the porous network during heating. This effect was also significant at dosages lower than the theoretical percolation threshold. These results are supported by permeability measurements carried out after various heat treatments and for various fibre dosages. They showed the striking effect of fibres from 200$^o$C up, that is, very close to their melting temperature. The role of fibres is discussed through the analysis of concrete microstructure and fibre-matrix interactions as function of heat treatment. The experimental work presented in this paper was based on the fact that PP fibres have been used in HPC constructions at a dosage of 2 kg/m$^3$ with the intention of reducing the propensity of concrete to spall, but that very few studies were carried out to understand the physical process through which fibres act against spalling, and to optimize the fibre dosage. Besides, fire tests carried out on columns and reported elsewhere showed that fibres had a significant effect at dosages as low as 0.9 kg/m$^3$, which is far below the theoretical percolation threshold.

The PTM tests carried out on fibre HPCs showed that fibres have a striking effect on the pressure fields that built up in the porous network during heating: as fibre dosage increased from 0 to 3 kg/m$^3$, pressure peaks were reduced by a factor of 4 and pressure gradients were reduced by a factor of 2. These effects were mostly pronounced between 0 and 1.75 kg/m$^3$ and less pronounced between 1.75 and 3 kg/m$^3$. Considering the theoretical work by Garboczi et al (30), this change in fibre effect around 1.75 kg/m$^3$ may be related to the fact that fibres have reached the percolation threshold at that dosage.

The permeability measurements carried out after various heat treatments and for various fibre dosages supported the results of the PTM tests. They showed the striking effect of fibres from 200$^o$C up, which is very close to their melting temperature: for a dosage of 3 kg/m$^3$, the intrinsic permeability (k) increased by a factor of 600 between 80$^o$C and 200$^o$C; at 200$^o$C, k increased 85 times as fibre dosage increases from 0 to 3 kg/m$^3$. At that temperature, the melted PP cannot be evacuated. The polymer is certainly absorbed by the surrounding matrix, partially or totally, as brought to light by the simple droplet test that was carried out, as well as by SEM observations. The rapid increase in permeability with temperature enables the evacuation of vapour and gases, thus releasing the pressure. Complementary permeability measurements should be performed between 100$^o$C and 170$^o$C in order to assess the role of fibres before they melt.

The relative contribution of fibres to mass transport decreased at 400$^o$C, as a result of the evolution of the microstructure; slight increase in porosity and above all micro cracking. The latter appeared to be significantly influenced by the presence of fibres: at 3 kg/m$^3$, micro cracking was characterized by a higher density and by smaller cracks than in plain concrete. A satisfactory explanation of this phenomenon was not found yet. It may have a significant effect on spalling as it may change the local stress distribution. Further microstructure analysis should be done between 100$^o$C and 170$^o$C[3].

**Vishwanath K. N., Suresh N.** in their paper entitled **"Fly ash composite concrete under sustained elevated temperature"**, have studied the role of fly ash on the behavior of hardened concrete with partial replacement of cement with fly ash in compression under sustained elevated temperatures. The capable contribution of fly ash concrete (FAC) in maintaining or improving the property of hardened concrete in compression under sustained temperature was tested. With replacement levels of 35 %, 40% & 45% by mass of cement, 4 mixes were cast. After curing they were exposed to temperatures 200 $^{o}$ C and 300 $^{o}$ C sustained for period of 5 hours. The specimens were allowed to cool to room temperature and then tested under compression .The results of X-ray diffraction tests done, show that elevated temperatures in this range favour CSH formation and the consumption of CH in the presence of fly ash. Based on the compressive strength, it could be concluded that blending with fly ash is a viable technique to sustain concrete at elevated temperatures [4].

**Md. AkhtarHossain, Mohammad Nural Islam, Md. RajibulKarim,** in their paper entitled **"Fire resistance of cement mortar containing high volume fly ash",** are of the opinion that the properties of materials used in preparing concrete play an important role on the performance of concrete during its lifetime. Terrorist attack, accidental fire breakout and different type of explosions produce a rapid change of temperature for a short period. In such a situation, the material properties play an important role in minimizing the potential damage due to high-rise of temperature. In recent days, the use of fly ash has been rapidly increased due to need of high performance concrete. The paper aims at studying the effect of high temperature during fire on the bond and compressive strength of cement mortar containing high volume fly ash without using any water reducing admixtures. To fulfill the goal, 2" cubes of cement mortar (1:2.75) with the inclusion of different percentage of fly ash are prepared, cured for 28 days, heated at different elevated temperature, cooled down at room temperature and finally tested in the laboratory. The test results indicate that the mortar containing 50% fly ash as a replacement of cement exhibits greater resistance to high temperature. Also, compressive and bond strengths of mortar containing different percentage of fly ash initially increase with the increase of temperature but after 200$^{o}$C they decrease with the further increase of temperature.

Throughout the world, research works have been performed on the properties of high volume fly ash concrete like strength, durability, corrosion of reinforcement, drying shrinkage, thermal cracking, etc. In the present study, the experimental investigations are carried out on cement mortar cubes with the inclusion of different percentage of fly ash as a replacement of cement. From the extensive experimental and theoretical study, the following conclusion may be drawn.

-Compressive and bond strength of cement mortar increase with the increase of percentage of fly ash up-to 50% and after that they decrease with the further increase of percentage of fly ash as a replacement of cement.

-Compressive strength of cement fly ash mortar initially increases up-to 200$^{o}$C temperature and after that it decreases with the further increase of temperature.

-Bond strength of cement fly ash mortar initially increases up-to definite temperature and then decreases with the increase of temperature [5].

**PothaRaju M., Shobha M. andRambabuin K.** in their paper entitled **"Flexural strength of fly ash concrete under elevated temperatures"**, have undertaken a study on heat-induced changes in fly ash concrete. The structural property of concrete that has been studied most widely as a function of heat exposure is compressive strength. Less attention has been given to flexural strength as influenced by heat exposure. Therefore, to investigate the effect of temperature on the flexural strength of fly ash concrete, the present study was carried out with M28, M33 and M35 grades of concrete. Concrete specimens l00mm x100mm X 500 mm with partial replacement of cement by fly ash (10%, 20% and 30% replacement levels) were heated to 100$^{o}$C, 200 and 350$^{o}$C for 1 h, 2h and 3 h duration in an electric oven. The fly ash concrete showed consistently the same pattern of behavior as that of concrete without fly ash under elevated temperatures during flexure. The fly ash concrete with fly ash content up to 20% showed improved performance compared with the specimens with out fly ash by retaining a greater amount of its strength [6].

**Savva A. , Manita P., Sideris K.K.** in their paper entitled **"Influence of elevated temperatures on the mechanical properties of blended cement concretes prepared with limestone and siliceous aggregates"**, have studied the influence of high temperatures on the mechanical properties and properties that affect the measurement by non-destructive method (rebound hammer and pulse velocity) of concrete containing various levels (10% and 30%) of Pozzolanic materials. Three types of pozzolans, one natural pozzolan and two lignite fly ashes (one of low and the other of high lime content) were used for cement replacement. Two series of mixtures were prepared using limestone and siliceous aggregates. The W/b and the cementitious material content were maintained constant for all the mixtures. Concrete specimens were tested at 100, 300, 600 and 750$^{o}$C for 2 h without any imposed load, and under the same heating regime. Results indicate that the residual properties of concrete strongly depend on the aggregates' and the binder type. Relationships between strength of concrete as well as rebound and pulse velocity versus heating temperatures are established. The above results are evaluated to establish a direct relationship between non-destructive measurements and compressive strength of concrete exposed to fire [7].

**Chi-Sun Poon, Salman Azhar, Mike Anson, Yuk-Lung Wong** in their paper entitled **"Performance of metakaolin concrete at elevated temperatures"**, have conducted the experiments to evaluate the performance of metakaolin (MK) concrete at elevated temperatures up to 800$^{o}$C.Eight normal and high strength concrete (HSC) mixes incorporating 0%, 5%, 10% and 20% MK were prepared. The residual compressive strength chloride-ion penetration, porosity and average pore sizes were measured and compared with silica fume (SF), fly ash (FA) and pure ordinary Portland cement (OPC) concretes. It was found that after an increase in compressive strength at 200$^{o}$C, the MK concrete suffered a more severe loss of compressive strength and permeability-related durability than the corresponding SF, FA and OPC concretes at higher temperatures. Explosive spalling was observed in both normal and high strength MK concretes and the frequency increased with higher MK contents [8].

**Daniel L. Y. Kong' Jay G. Sanjayan'** in their paper entitled **"Effect of elevated temperatures on geopolymer paste, mortar and concrete",** have studied the effect of high temperature on geopolymer concrete. This paper presents the result of a study on the effect of elevated temperature on geopolymer paste, mortar and concrete made using fly ash as a precursor. The geopolymer was synthesized with sodium silicate potassium hydroxide solutions. Various experimental parameters have been examined such as specimen sizing, aggregate sizing, aggregate type and super plasticizer type. The study identifies specimen size and aggregate sizing as the two main factors that govern geopolymer behavior at elevated temperatures (800$^{o}$C). Aggregate sizes larger than 10 mm resulted in good strength performance in both ambient and elevated temperatures. Strength loss in geopolymer concrete at elevated temperatures is attributed to the thermal mismatch between the geopolymer matrix and the aggregates [9].

**Morsy M. S., Alsayed S. H. and Aqel M.** in their paper entitled **"Effect of elevated temperature on mechanical properties and microstructure of silica flour concrete"**, have studied an experimental investigation to evaluate the influence of elevated temperatures on the mechanical properties, phase composition and microstructure of silica flour concrete. The blended cement used in this investigation consists of ordinary Portland cement (OPC) and silica flour .The OPC were partially replaced by 0, 5, 10, 15 and 20% of silica flour. The blended concrete paste was prepared using the water-binder ratio of 0.5 wt% of blended cement. The fresh concrete paste were first cured at 100% relative humidity for 24 hours and then cured in water for 28 days. The hardened concrete was thermally treated at 100, 200, 400, 600 and 800$^{o}$C for 2 hours. The compressive strength, indirect tensile strength, phase composition and microstructure of silica flour concrete were compared with those of the pure ordinary Portland concrete. The result showed that the addition of silica flour to OPC improves the performance of the produced blended concrete when exposed to elevated temperatures up to 400$^{o}$C. The following conclusions can be drawn from the study;

- The studied silica flour has a very positive effect on the strength after thermal treatment at 400$^{o}$C for 2 hours.
- The pozzolanic reaction of silica flour is accelerated between 100 and 400$^{o}$C. This is accompanied by a steep decrease of Ca $(OH)_2$ content.
- Based on the mechanical and physical properties of silica flour concrete, it was observed that 20% silica flour concrete was generally more favorable than 5, 10 and 15%, and thus can be used in structural elements exposed to elevated temperature up to 400$^{o}$C[10].

**Xu Y., Wong Y.L., Poon C.S., Anson M.** in their paper entitled **"Impact of high temperature on PFA concrete"**, have studied the residual properties of pulverized fly ash concrete (PFA) when subjected to high temperatures. Both mechanical and durability properties of concrete were tested on concretes made with different water to binder ratios and PFA contents. Microscopic techniques were then employed and the pore structure and micro-hardness values of hardened cement paste were determined. The results of rapid chloride diffusion tests revealed that concrete durability deterioration commences after exposure to temperatures, which are lower than those at which compressive strength deterioration commences. The rise in compressive strength, which occurs after exposure to 250$^{o}$C, may be largely due to the hardening of cement paste caused by drying and the further hydration of cementitious materials. The simultaneous loss of durability, however, can be explained by a weakened transition zone between hcp and aggregate, and by the concurrent coarsening of the help pore structure. When PFA is included, an improvement of fire resistance as characterized by the residual compressive strength was observed, and this relative improvement over non-PFA concrete was the most pronounced for maximum exposure temperatures of 450$^{o}$C and 650$^{o}$C[11].

**Poon C.S., Shui Z.H., Lam L.** in their paper entitled **"Compressive behavior of fiber reinforced high-performance concrete subjected to elevated temperatures",** have studied the effect of elevated temperatures on the compressive strength, stress-strain relationship (stiffness) and energy absorption capacities (toughness) of concrete. High-performance concrete (HPCs) were prepared in three series, with different cementitious material constitutions using plain ordinary Portland cement (PC), with and without metakaolin (MK) and silica fume (SF) as separate replacements. Each series comprised a concrete mix, prepared without any fibers, and concrete mixes reinforced with either or both steel fibers and polypropylene (PP) fibers. The results showed that after exposure to 600 and 800°C, the concrete mixes retained, respectively, 45% and 23% of their compressive strength, on average. The results also show that after the concrete was exposed to the elevated temperatures, the loss of stiffness was much quicker than the loss in compressive strength but the loss of energy absorption capacity was relatively slower. A 20% replacement of the cement by MK resulted in a higher compressive strength but a lower specific toughness, as compared with the concrete prepared with l0% replacement of cement by SF. The MK concrete also showed quicker losses in the compressive strength, elastic modulus and energy absorption capacity after exposure to the elevated temperatures. Steel fibers approximately doubled the energy absorption capacity of the unheated concrete. They were effective in minimizing the degradation of compressive strength for the concrete after exposure to the elevated temperatures. The steel-fiber-reinforced concrete also showed the highest energy absorption capacity after the high-temperature exposure, although they suffered a quick loss of this capacity. In comparison, using PP fibers reduced the energy absorption capacity of the concrete after exposure to 800°C, although it had a minor beneficial effect on the energy absorption capacity of the concrete before heating [12].

## III. CONCLUSIONS

The study has shown that the blending of mineral admixtures (pozzolanas) with cement can enhance the resistance of cement towards high temperature.20% cement replacement by flyash can enhance the compressive and flexural strength of concrete when exposed to high temperature. The residual strength characteristics and durability characteristics (in the form of permeability test) are found improving with the usage of mineral admixtures at elevated temperatures.

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