International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 09 Issue: 06 | June 2022 www.irjet.net p-ISSN: 2395-0072

# FRESH, HARDENED AND DURABILITY PROPERTIES OF CONCRETE CONTAINING MINERAL ADMIXTURES: A REVIEW

**Batham Geeta[1], Akhtar Saleem[2], Rajesh Bhargava[3]**

*[1]PhD Scholar, UIT-RGPV, Bhopal, India,*
*[2] Professor, UIT-RGPV, Bhopal, India,*
*[3] Professor, RGPV, Bhopal, India.*

---***---

**Abstract -** Although various research have been conducted on use of mineral admixture in concrete still there are challenges regarding the selection of mineral admixture and its content in concrete for improving the characteristics of concrete as well as reducing the cement content. In this study, literature review has been conducted to investigate the effect of mineral admixtures such as fly ash, ultra-fine fly ash, silica fume, nano silica, metakaolin and ground-granulated blast furnace slag on fresh, hardened and durability properties of concrete. Review of work done by various researchers on use of mineral admixture in concrete are studied and compiled here. Study reveals that mineral admixtures fly ash, ultra-fine fly ash, ground-granulated blast furnace slag, increases workability, setting time whereas silica fume, and metakolin reduces workability and setting time. Fly ash, ultra-fine fly ash, metakolin, nano silica and ground-granulated blast-furnace slag increases strength properties such as compressive strength, flexural strength and tensile strength of concrete. Fly ash, ultra-fine fly ash, silica fume, nano silica, GGBS, metakaolin increases resistance to chloride permeability, aggressive chemicals and corrosion. It was also found that concrete shows increased resistance to fresh, hardened and durability properties when mineral admixtures are used with fine and ultrafine materials.

**Keywords**: Fly ash, ultra-fine fly ash, silica fume, nano silica, metakaolin, ground granulated blast furnace slags, fresh, hardened and durability properties.

## 1. INTRODUCTION

Mineral admixture are widely used in concrete for various reasons especially for reducing the amount of cement required for making concrete which shows to a reduction in construction cost. Moreover most pozzolanic materials are byproduct materials. The use of these materials shows the reduction in waste, freeing up valuable land, save in energy consumption to produce cement and save the environment. Durability of Portland cement concrete is defined as its ability to resist weathering action, chemical attack, abrasion, fire or another process of deterioration. In other words, cement concrete will be termed durable, when it keeps its form and shape within the allowable limits, while exposed to different environmental conditions. Durability of concrete has been a major concern of civil engineering professionals. Also, it has been of considerable scientific and technological interest over the last few decades [Park Y. S. et. al., 1999] 1 and [Nehdi M., 2005] 2.

Concrete is the most common durable material used in construction industry. Durability is an important parameter when structural reinforced concrete is used in harsh environments. The environmental factors such as weathering action, chemical attack, abrasion and other deterioration process may change the properties of reinforced concrete with time. The degrees of deterioration occurs is mainly due to the presence of pore size in the concrete. Concrete with Supplementary Cementitious Material (SCM) like Metakaolin (MK) and Nano Silica (NS) will help in producing the concrete with a dense microstructure, which will decrease the voids in concrete [Prabakar, 2019]3.

The presence of high workability, durability and strength, are what qualifies concrete to be termed as high performance concrete. The rising need for high performance concrete in the construction industry, globally, has necessitated the exploration of different means to enhance concrete to this level of optimum performance. Durability can be improved through the use of supplementary cementitious materials. High volume fly ash is known to improve the durability of high strength concrete and nano silica efficiently improves the strength [Shashikumar and Keshavamurthy, 2019]4. High Performance Concrete (HPC) is the latest development in concrete. It has become more popular these days and is being used in many prestigious projects. Mineral admixtures such as fly ash, rice husk ash, metakaolin, silica fume etc are more commonly used in the development of HPC mixes. Addition of such materials has indicated the improvements in the strength and durability properties of concrete. The utilization of calcined clay, in the form of high reactivity metakaolin (HRM) in concrete has received considerable attention in recent years [BB patil and PD kumbhar, 2012]5. Mineral admixtures such as fly ash, rice husk ash, metakaolin, silica fume etc. are more commonly used in the development of high performance concrete mixes. They help in obtaining both higher performance and economy. These materials increase the long term performance of the high performance concrete through reduced permeability resulting in improved durability [K. A. Gruber et. al., 2001] 6.

## 2. BACKGROUND AND MANUFACTURING OF MINERAL ADMIXTURES

### Fly ash

McMillan and powers were the first who used coal FA in concrete in [Thomas et. al., 1934]7. After them, based on the research work conducted during the 1950s by [ Fulton and Marshall, 1956]8. Lednock, Clatworthy and Lubreoch Dams had been constructed in the UK using FA as a partial cementitious material, and since then, these structures have been reported in excellent conditions [Newman, 2003]9. Fly ash particles are almost totally spherical in shape, allowing them to flow and blend freely in mixtures. That capability is one of the properties making fly ash a desirable admixture for concrete. These materials greatly improve the durability of concrete through control of high thermal gradients, pore refinement, depletion of cement alkalis, resistance to chloride and sulphate penetration, and continued micro structural development through a long-term hydration and pozzolanic reaction. The utilization of by-products as the partial replacement of cement has important economical, environmental and technical benefits such as the reduced amount of waste materials, cleaner environment, reduced energy requirement, durable service performance during service life and cost effective structures [Patil S. L. et. al., 2012]10.

FA is produced when coal is burnt during power generation about 1600∘ C (2912∘ F) [ACI Committee, 2003]11. This burning also results in some incombustible materials which amalgamate to form spherical glassy droplets of silica ($SiO_2$), alumina ($Al_2O_3$), iron oxide ($Fe_2O_3$), and other minor constituents. According to ASTM C 618-05, there are two classes of FA based on the types of coal from which it originates. The Class F is produced by burning anthracites which is mainly a siliceous and possesses pozzolanic characteristics. The Class C contains lime and higher MgO content and it is produced by burning lignite and subbituminous coal. Class C fly ash is lighter in colour in comparison with other ashes and may cause expansion and their strength behaviour at high temperature is not apparent [ACI Committee, 1984]12 and [Neville and brooks, 2010]13.

### Ultra-fine fly ash

The ultra-fine fly ash is obtained by post-processing of coal 104 combustion fly ashes by the Dusty Plasma Separation (DPS) technology. A proprietary 0.2 105 tonne/h prototype DPS was used [Loots, 2017]14–[Boonen, 2018]15. UFFA is being commercially manufactured with a mean particle diameter of approximately 3 microns. The high silica content and sum of oxides ($SiO_2$ + $Al_2O_3$ + $Fe_2O_3$) are similar to what would be expected for a Class F FA as per ASTM C 618 designation. Processing FA into an ultra-fine material with a refined particle size distribution clearly improves its performance as a durability-enhancing admixture [Obla et. al., 2003]16.

In the device fly ashes are separated based on particle 106 size in a dry, closed system. The principle of separation uses a combination of air drag and 107 charging forces to separate the particles. Compared to conventional air classifiers the DPS 108 device has a lower per tonne energy consumption of about 15 kWh/t and experience less 109 abrasion during operation. The DPS devices classifies fly ash in four main size fractions: fine 110 fly ash (FA1), ultra-fine fly ash (FA2), and medium and coarse fly ash fractions [Maeijera et. al., 2020]17.

### Silica fume

In 1947, SF was first obtained in Norway, during filtration of the exhaust gases from furnaces as fumes. The large portion of these fumes contained very fine powder of high percentage of silicon dioxide. Since the 1970s, filtration of gases has started at large scale and, in 1976, first standard NS 3050 was granted to use SF in factory-produced cement, extensive literature is available on SF and SF concrete [Newman, 2003]9. Silica fume is an amorphous polymorph of silicon dioxide, silica. It is collected as a byproduct of producing silicon metal or ferrosilicon alloys. One of the unique properties of silica fume is its high surface area. It is a very good pozzolanic material and hence finds its use in high performance concrete. Concrete containing silica fume can have very high strength and can be very durable. Silica fume is often added to the concrete as admixtures or partial replacement of cement. [A. Lahri and Dr. Savita Dixit, 2015]20.

SF is a by-product obtained after reducing high-purity quartz with coal in electric arc furnace by heating up to 2000◦ C (3632◦ F) during the production of silicon. By oxidation and condensation of exhaust gas SiO, very fine spherical particles of SF are obtained which are highly reactive with the Ca(OH)2 produced during hydration of cement [Newman, 2003]9. It is a high quality material used in the cement and concrete industry. It has been reported that if a typical dosage of SF of 8–10% by weight of cement is added in concrete, then its effect is between 50,000 and 100,000 microspheres percent particle; that is, concrete mix will be denser and cohesive due to fine particles of SF [Thomas et. al., 1934]7.

**Nano-silica**

Nano-SiO2 is a white fluffy powder composed of high purity amorphous silica powder. Because of its small particle size, nano-SiO2 had the advantages of large specific surface area, strong surface adsorption, large surface energy, high chemical purity and good dispersion. Nano-materials [Alkhatib, 2020]18 enhance the particle size distribution in concrete leading to an efficient particle packing and improved denseness and strength. The use of nano-materials will also decrease the diffusion of aggressive species, such as chloride, sulfate, carbon dioxide, etc., thereby increasing the durability of concrete.

**Metakaolin**

Kaolin is naturally occurring material; the chemical and mineralogical compositions are highly dependent on the rock from which it is formed [Baioumi]23. Kaolin is widely occurring white clay resulting from natural decomposition of feldspar and is mainly used in the manufacturing of porcelain, as a filler in the paper and textiles, and as absorbent in medicines [Newman, 2003]9. Metakaolin is a dehydroxylated form of the clay mineral kaolinite. It is an amorphous non crystallized material which consists of lamellar particles. Research on Metakaolin shows that it is an excellent pozzolanic material which can improve strength, durability and other mechanical properties of concrete. [A. Lahri and Dr. Savita Dixit, 2015]20.

Kaolin is converted into MK when it is heated to the temperature between 600 and 850◦ C (1112 to 1562◦ F) [Shavarzman et. al., 2003]19. The temperature of calcination and duration depended on the mineralogical composition of raw kaolin. It has been reported that higher alunite content in kaolin requires higher temperature of calcination and low alunite content gives good calcined kaolin on low temperature [Badogiannis et. al, 2005]21 and [Guneyisi, 2012]22. MK is a very reactive pozzolan, but its physical and chemical characteristics greatly depend on the raw material used, the temperature during calcination and finishing process [Newman, 2003]9.

**Ground granulated blast furnace slag**

In 1862, GGBS was first discovered in Germany by Emil Langen; however, commercial production of lime-activated GGBS was started in 1865 in Germany. Around 1880, GGBS was first used with Portland cement (PC). Since then it has been used extensively in many European countries. In the UK, the first British standard for Portland blast furnace cement (PBFC) was introduced in 1923 [Newman, 2003]9.

Ground-granulated blast-furnace slag also known as GGBS is obtained from molten iron slag which is a by-product of iron and steel-making. The process involves quenching of iron slag from a blast furnace in water or steam, to produce a glassy, granular product that is then dried and ground into a fine powder. This fine powder is then called as Ground-granulated blast-furnace slag. [A. Lahri and Dr. Savita Dixit, 2015]20.

## 3. LITERATURE REVIEW

A no of studies have been conducted on use of mineral admixture in concrete. The literature review of the latest studies are as follows.

**3.1 Fresh properties of concrete containing mineral admixtures**

[Wankhede P. R. and Fulari V. A., 2014] 9 observed that the slump loss of concrete kept on increasing with the increase of quantity of fly ash. [Yash Shrivastava and Ketan Bajaj, 2012]12 produced HVFA concrete grades M20, M50 and M70 using class c fly ash with target mean strength of 26.25 MPa, 56.36 MPa and 78.69 MPa. Replacement of cement by fly ash was found to be 20%, 35%, 50% and 70%. Author reported increase in workability and found optimum percentage of fly ash content for workability 50 % and 55%. The results showed that up to 50% replacement of cement can be used for construction with in addition reduces 12% overall cost. [P. Sravana, and P. Srinivasa Rao, 2006]13 conducted test on M20, M30, M40, and M50 grades of concrete containing fly ash as mineral admixture and found reduction in workability, therefore super plasticizer dosage was used to maintain the workability. [Sarath Chandra Kumar and Bendapudi P. Saha, 2011] 17 prepared detailed literature on contribution of high volume fly ash to the properties of mortar and concrete and found fly ash is an effective pozzolan which contributes to the properties of concrete. Fly ash blended concrete improve the workability of concrete compared to OPC. It also increase the initial and final setting time of cement pastes. [Vanita Aggrawal et. al., 2010]18 reviewed concrete properties of high volume fly ash concrete and found that percentage of replacement of cement is increased the with decrease in water/ binder ratio. [J. Hoppe Filho et. al. 2013]22 observed that lower w/c ratio results in increase in binding material consumption which was 24 % and 18 % for concrete containing 50 % fly ash and 50 % fly ash with 20 % additional hydrated lime respectively as compared to control concrete. Although corresponding decrease in Portland cement were also observed which was 38 % and 41 % for both concrete respectively.

[Maeijer et. al., 2020]23 conducted experimental study to investigate the effect of two types ultrafine fly ash one with particle size d90 < 9.3 7 µm (FA1) second with d90 < 4.6 µm (FA2) for replacement of two types cement Portland cement and slag cement for concrete and mortar. Percentage replacement of cement for mortar were 0%, 15%, 25%, 35%, 50% and for concrete 0%, 15% , 25% for both type ultra-fine fly ash. Study reveals that incorporation of ultrafine fly ash (d90 < 4.6 µm) results in increased fineness, better workability. [Obla et. al., 2003]24 investigated and compared properties of silica fume concrete and ultra-fine fly ash concrete. It was found that at a given workability and water content, concrete containing UFFA could be produced with only 50% of the high-range water reducer dosage required for comparable silica fume concrete. [Hu Jin et al., 2014]29 investigated properties of high strength concrete by replacing cement by super-fine fly ash (25%) and lime stone powder (10%). Result showed concrete containing super-fine FA and lime stone powder can get a larger initial slump loss than control mix with same amount of plasticizer content.

[Ghutke V. S. and Bhandari P. S., 2014]30 investigated that workability of concrete decreases with the increase in percentage of silica fume. [Roy D. K. S. and Sil A., 2012]31 concluded that silica fume helps in achieving lower water-cement ratio and better hydration of cement particles. [Amudhavalli N. K. and Mathew J., 2012]33 performed experiments on M35 grade concrete, partially replacing cement by silica fume by 0%, 5%, 10%, 15%, 20% and found consistency of cement increases upon addition of silica fume to the concrete. [Pradhan D. and Dutta D, 2013]34 found compacting factor ranged from 0.82 to 0.88 and the slump value from 20 to 50 mm when silica fume was added in different proportion to the concrete.

[Zhuang and Chen, 2019]38 prepared a literature summary on influence of nano-SiO2 on concrete properties. Study reveals that the setting time of nano-SiO2 concrete is shortened, the slump is reduced.

[Suryawanshi Y. R. et al., 2015]42 investigated the effects of metakaolin and super plasticizer on concrete for grade M-35. The replacement percentage were 4, 8, 12, 16 and 20%. The water cement ratio was taken as 0.43 for all cases and compressive strength at 3, 7 and 28 days was determined. It was observed that use of metakaolin reduces the workability but use of suitable super plasticizers can compensate this reduction. [Patil B. B. and Kumbhar P. D., 2012]5 found optimum percentage of metakaolin for workability as 7.5 % for M 60 grade of concrete. Devi [44] used metakaolin from 5% to 20% as a partial replacement of cement and found that incorporation of metakaolin in quarry dust concrete improved the rheological properties of concrete like workability, compactability, bleeding and segregation.

[Arivalagan S., 2014]47 found addition of GGBS up to 40% cement gave normal workability of M-35 concrete as compare to OPC concrete. [Tamilarasan V. S. et. al., 2012]49 prepared M20 and M25 grade concrete with partial replacement of cement from 0 to 100 % by GGBS. It was found that the workability of concrete improved up to 45% replacement for grade M20 grade and up to 50% replacement for grade M25 grade of concrete. Author found workability of M25 grade better than that of M20 grade of concrete.

### 3.2 Fresh properties of concrete in containing mineral admixtures with fine and ultrafine materials

[Nochaiya T. et. al., 2010]52 examined the effects of adding silica fume in Portland cement concrete incorporated with fly ash. The percentages of fly ash used were 5%, 10%, 20% and 30% and percentages of silica fume used were 2.5%, 5%, and 10. . It was found that on increasing the silica fume content in concrete, the water requirement for normal consistency increases, initial setting time decreases and workability reduces but remained higher than that of Portland cement concrete. [Nazeer M. and Kumar R. A., 2014]55 prepared high-volume fly ash concrete blended with metakaolin. Fly ash used as partial replacement of cement in Portland cement concrete was 50% by weight. Metakaolin was used to replace the remaining cement by 5%, 10%, 15% and 20%. The concrete mix was formed for grade M30 with water binder ratio as 0.44 and two curing conditions i.e. boiling and normal curing were used. It was observed that the workability of concrete blended with fly ash and metakaolin was lower than that of controlled Portland cement concrete. [Patil et. al., 2015]56 evaluated workability of high performance self-compacting concrete incorporated with a combination of fly ash and metakaolin. The fly ash was used in proportions of 5%, 15% and 25% and metakaolin was used in proportions of 3%, 6% and 9%. It was observed that fly ash increases the workability of concrete. [Muthupriya P. et. al., 2011]57 studied the behavior of high performance reinforced concrete column made with metakaolin and fly ash as a partial replacement of ordinary Portland cement. Concrete mixes were formed by using 10% fly ash and different percentages of metakaolin for long and short columns. Less segregation, less rate of water absorption and more cohesion were observed in concrete containing fly ash and metakaolin as compared to normal concrete mix. **[**Tilo Proske et. al. ,2014]61 investigated the effect of mineral addition such as fly ash, GGBS and limestone powder on fresh concrete properties with low cement and water content. It was found that concretes with cement contents lower than 125 kg/m$^3$ were able to meet the usual required workability. [S. Abbas et. al., 2016]65 studied various research papers and prepared a database on the material characterization of UHPC and its potential for large-scale field applicability. Author found Fly ash acts as a perfect water reducer with improved workability and increased setting time. Srivastava V. et al, 2012]66 used a combination of silica fume and metakaolin in Portland cement concrete and found addition of metakaolin also reduced the slump in concrete. [Dale P. Bentz, 2012]70 prepared HVFA mortar using three limestone powders, nano-limestone ( 5 %),lime stone having median particle diameters of 4.4 µm (5-10 %) and 16.4 µm using class C fly ash (5 %) and silica fume 5 %. Author found 5% replacement of nano-limestone for cement on a volume basis, accelerates the early age reactions and reduces initial and final setting time. Particle sizes of the limestone powders influences reaction and setting time. Nano-limestone found highly efficient.

### 3.3 Hardened properties of concrete containing mineral admixtures

[Wankhede P. R. and Fulari V. A., 2014]24 found increment in compressive strength at 10 % and 20 % replacement of cement whereas decrement in strength at 30 %. [Patil S. L. et. al. 2012]10 replaced cement with fly ash from 5% to 25% and found increment in compressive strength at 5 % and 10 % at 21 days curing 90 days curing respectively and maximum rate of compressive strength development is maximum at 60 days for concrete with no replacement. [Bremseth S. K., 2010]25 found greatest disadvantage of using fly ash in concrete as lower rate of strength gain. [P. Sravana, and P. Srinivasa Rao, 2006]26 conducted test on M20, M30, M40, and M50 grades of concrete containing OPC and studied the effect of thermal cycles (7, 28, 45 and 90) to the concrete produced at different temperatures. Author found that concrete containing fly ash addition was more effective in resisting the effect of thermal cycles than ordinary and fly ash replace cement concrete. [Soni D. K. and J. Saini, 2014]27 investigated effect of 30 %, 40 % and 50 % mineral addition in concrete on strength at high temperatures 80˚C, 100˚C, and 120˚C at 28 and 56 days of curing. Test results showed that the compressive strength, split tensile strength and modulus of elasticity of concrete having cement replacement up to 30% was comparable to the reference concrete without fly ash. With the increase in temperature, compressive strength of concrete mixes with 30%, 40% and 50 % of fly ash as cement replacement decreases by 11.4%, 30.1%, 28.9% and 27.5% at 120˚C when compared to room temperature. [Sarath Chandra Kumar and Bendapudi P. Saha, 2011]28 prepared detailed literature on contribution of high volume fly ash to the properties of mortar and concrete and found the higher is the compressive strength of concrete, the lower is the ratio of splitting tensile strength to compressive strength. [T.P. Singh, 2007]29 shared experience in field performance of high volume fly ash concrete and found that HVFAC has superior compressive strength, flexural strength, elastic modulus, abrasion resistance [Vanita Aggrawal et. al., 2010]30 reviewed concrete properties of high volume fly ash concrete and found that incorporation of fly ash results in decrement in compressive strength at initial days of curing and drastic increment in compressive strength at higher days of curing. It was observed that at 40 % replacement of cement 28 days compressive strength was lower but at 90 days of curing strength gain was higher. [Rafat Siddiue, 2013]31 replaced 35 %, 45%, 55% fine aggregate using high volume class F fly ash and found all three mixes shows improved resistance for compressive strength, splitting tensile strength, flexural strength modulus of elasticity and abrasion test than control mix at all days of curing. [Zaldiwar et.al., 2013]32 conducted research program to study the effect of grinding time on 10 %, 20% and 30% ground fly ash and found milling time has an effective increase on compressive strength of concrete.

[Qiang Wang et. al., 2013]33 incorporated blended steel slag super fine fly ash as mineral admixture in concrete and compared the performance with concrete containing ordinary fly ash. Result indicated that incorporation of blended steel slag super fine fly ash in concrete has higher ability to improve the late strength of concrete than ordinary fly ash. [Luigi Coppola et al., 2018]34 used five different types of cement with siliceous fly ash (FA) or ultrafine fly ash (UFFA) to produce mortar. Replacement percentage were 5%, 15%, 25%, 35%, and 50% of cement mass. Results indicated that compressive strength of mortars with UFFA is considerably higher than that of mixtures containing traditional Fly Ash, both at early and later days of curing. Moreover, experimental data reveal that replacement of cement with up to 25% of UFFA determines higher compressive strength at 7, 28, and 84 days than plain mortars, regardless of the type of cement used. Mortars manufactured with 35% or 50% of UFFA show slightly lower or similar compressive strength compared to the reference mortar. [Roychand et. al., 2016]35 investigated properties of class F high volume ultra-fine fly ash (HV-UFFA of size 8.1 μm) cement composites, replacing 80 % of opc cement by silica fume and nano silica individually and in combination of with additives (set accelerator and/or hydrated lime). Study reveals that compressive strength of HV-UFFA cement mortar improves with silica fume in combined with additives however with nano silica compressive strength improves without additives as compared to OPC mortar. The improvement in compressive strength of silica fume and nano silica was found by 273%, 413 % and 918%, 567% at 7 days and 28 days of curing respectively. Nano silica with additives results in micro cracking and therefor hindering development of compressive strength. [Faiz U.A. Shaikh and Steve W.M. Supit, 2015]36. [Ghutke V. S. and Bhandari P. S., 2014]37 investigated the optimum replacement percentage for compressive strength varies between 10 to 15%, after 15% the compressive strength decreases. [Roy D. K. S. and Sil A., 2012]38 found 10% replacement of cement with silica fume gave the maximum compressive strength and also gave significant increase in tensile and flexural strength. High early strength is achieved in silica fume concrete. [Srivastava V., 2013 ]39 reviewed the effects of silica fume in concrete and concluded that incorporation of silica fume increases the compressive strength and bond strength of concrete and other properties such as tensile strength, flexural strength and modulus of elasticity of silica fume concrete are comparable to that of Portland cement concrete. [Amudhavalli N. K. and Mathew J., 2012]40 performed experiments on M35 grade concrete, partially replacing cement by silica fume by 0%, 5%, 10%, 15% and 20%. The increase in flexural strength was observed upto 15% replacement of cement by silica fume. The gain in split tensile strength was significant upto 10 % silica fume. The optimum compressive and flexural strength was obtained in the range of 10-15% replacement of cement by silica. [Pradhan D. and Dutta D, 2013]41 found optimum compressive strength at 20% replacement of cement by silica fume. [Shanmugapriya T and Uma R. N., 2013]42 carried out experiments on concrete with mean strength of 60Mpa having a water binder ratio as 0.32 and using CONPLAST SP 430 super plasticizer. The percentage increment were found 15%, 20 % and 23 % for compressive strength, tensile strength and flexural strength respectively. Optimum dosage was found 7.5 % for maximum performance of concrete.ed the effect of ultrafine fly ash on compressive strength of concretes containing high volume class F fly ash as partial replacement of cement. The compressive strengths are measured at 3, 7, 28, 56 and 90 days. Results show high volume fly ash concrete containing 32% fly ash and 8 % ultra-fine fly ash exhibited superior compressive strength. [L. Krishnaraj and P. T. Ravichandran, 2020]43 conducted experimental program to understand the strength improvement of ultra-fine fly ash particles. It was found that the ultra-fine fly ash masonry block shows higher compressive strength, higher resistance to shear, higher bonding between two bricks compare to conventional masonry blocks. [Hu Jin et al., 2014]44 Investigated properties of high strength concrete by replacing cement by super-fine fly ash (25%) and lime stone powder (10%) and found early strength lower but late strength showed almost same level of performance.

[Ghutke V. S. and Bhandari P. S., 2014]37 investigated the optimum replacement percentage for compressive strength varies between 10 to 15%, after 15% the compressive strength decreases. [Roy D. K. S. and Sil A., 2012]38 found 10% replacement of cement with silica fume gave the maximum compressive strength and also gave significant increase in tensile and flexural strength. High early strength is achieved in silica fume concrete. [Srivastava V., 2013 ]39 reviewed the effects of silica fume in concrete and concluded that incorporation of silica fume increases the compressive strength and bond strength of concrete and other properties such as tensile strength, flexural strength and modulus of elasticity of silica fume concrete are comparable to that of Portland cement concrete. [Amudhavalli N. K. and Mathew J., 2012]40 performed experiments on M35 grade concrete, partially replacing cement by silica fume by 0%, 5%, 10%, 15% and 20%. The increase in flexural strength was

observed upto 15% replacement of cement by silica fume. The gain in split tensile strength was significant upto 10 % silica fume. The optimum compressive and flexural strength was obtained in the range of 10-15% replacement of cement by silica. [Pradhan D. and Dutta D, 2013]41 found optimum compressive strength at 20% replacement of cement by silica fume. [Shanmugapriya T and Uma R. N., 2013]42 carried out experiments on concrete with mean strength of 60Mpa having a water binder ratio as 0.32 and using CONPLAST SP 430 super plasticizer. The percentage increment were found 15%, 20 % and 23 % for compressive strength, tensile strength and flexural strength respectively. Optimum dosage was found 7.5 % for maximum performance of concrete.

[Isfahani, 2016]37 et. al. investigated strength properties of concrete using 0.5%, 1%, 1.5% nano silica for water/binder ratios 0.65, 0.55, and 0.5. Study reveals that incorporation of 1.5 % nano silica results in increased compressive strength by 41 % and 6.5% for concrete with w/b raio 0.65 and 0.55. The effectiveness of a certain nano silica dosage addition into lower strength mixes was more noticeable, while, for the higher strength mix, the effectiveness was less. [Zhuang and Chen, 2019]38 prepared a literature summary on influence of nano-SiO2 on concrete properties and found that nano-SiO2 shows limited improvement in the mechanical properties of concrete. [Andrade et al., 2020]40 studied the effect of nano-silica on the ternary system of rice husk ash, silica fume and Portland cement. It was reported that the quaternary mixtures containing nano-silica exhibited maximum compressive strength. [Madhusudan et al., 2019]41 prepared concrete containing micro-silica upto 7% and nano-silica 2 % and properties were compared with conventional concrete. Study indicated that the combination of micro-silica and nano-silica increased both the compressive and flexural strength of concrete, culminating from the pore refinement caused due to the addition of MS and NS.

[Suryawanshi Y. R. et al., 2015]42 investigated the effects of metakaolin and super plasticizer on concrete for grade M-35. The replacement percentage were 4, 8, 12, 16 and 20%. The water cement ratio was taken as 0.43 for all cases and compressive strength at 3, 7 and 28 days was determined. The compressive strength increased up to cement replacement of 12% after which a decrease in compressive strength was observed. [Patil B. B. and Kumbhar P. D., 2012]5 investigated the effect of metakaolin on concrete for M60 grade. Optimum percentage for compressive strength was found 7.5%. In this particular research, the high reactivity metakaolin samples have silica and alumina content of 81%. It is considered that the high reactivity metakaolin has a high purity and high kaolinite content. As a result, 7.5% addition attains the highest compressive strength in 28 days. [Prabakar, 2019]1 carried out experimental investigation to study the effect of metakaolin in M25 and M50. Nano silica were added to enhance the properties of concrete. Replacement percentage for metakaolin and nano silica by weight of cementitious materials were 0%, 5%, 10%, 15%, 20% and 0.5%, 1%, 1.5%, 2% respectively. Study indicated that maximum increase in compressive strength were found at 10 % metakaolin which was 44.4% and 26 % higher than the control concrete for grade M25 and M50 respectively. Addition of 1.5% nano silica in M25 grade concrete and 2 % nano silica in M50 grade concrete showed 74 % and 48% higher strength than the control concrete. Author found combination of the optimum percentage of metakolin and nano silica addition show good enhancement in the mechanical properties when compared to control concrete. [Badogiannis E. et. al., 2002]43 used two categories of metakaolin first produced metakaolin and second commercially available high purity metakaolin to replace cement in the concrete. It was observed that both metakaolin exhibited higher 28 days and 90 days strength, but strength development was similar to those of Portland cement concrete. [Devi, 2015]44 used metakaolin from 5% to 20% for partial replacement of cement and found optimum percentage 15% which enhanced the strengths.

[Awasare V. and Nagendra M. V., 2014]46 analyzed the strength characteristics of a M20 grade concrete using natural sand and crushed sand. Replacement percentage of cement with GGBS were 20%, 30%, 40% and 50%. It was observed that incorporation of GGBS in concrete improves flexural strength and tensile strength performance. The optimum strength of concrete for both natural and crushed sand is achieved at 30% replacement of cement with GGBS. [Arivalagan S., 2014]47 observed that the strength at 28days of the concrete increases for 20% replacement of cement with GGBS for M-35 grade. [Ramezanianpour et. al. A. A., 2013]48 replaced GGBS 35%, 42.5% and 50. It is also observed that a lower w/c ratio indicates a higher compressive resistance.

### 3.4 Hardened properties of concrete containing mineral admixtures with fine and ultrafine materials

[Mohamed H. A., 2011]51 prepared self-compacting concrete incorporated with different percentages of fly ash, silica fume and combination of fly ash and silica fume. Cylinder specimens were used for slump and V-funnel test. The experiment involved different curing conditions for different specimens. Concrete having 15 % fly ash and cured in water for 28 days achieved the maximum compressive strength. 10 % fly ash and 10% silica fume were found to be optimum. [Nochaiya T. et. al., 2010]52 examined the effects of adding silica fume in Portland cement concrete incorporated with fly ash. The percentages of fly ash used were 5%, 10%, 20% and 30% and percentages of silica fume used were 2.5%, 5%, and 10%. An overall increase in compressive strength was observed in concrete on utilization of silica fume in concrete incorporated with fly ash. [Wongkeo W. et. al., 2014]53 evaluates the influence of high-calcium fly ash and silica fume on self-compacting concrete (SCC). The percentages of fly ash used ranges from 40 to 70% where as that of silica fume ranges from 0 to 10%. The optimum percentage of fly ash was found to be 40% when used with 10% silica fume at water-cement ration of 0.3. [S. Lokesh et. al., 2013]54 use fly ash aggregate to replace natural aggregates with combination of cement and silica fume. Author prepared three trial mixes for M25 grade of concrete using light weight fly ash aggregate, natural aggregates, fly ash and silica fume with water cement ratio 0.3. Compressive strength of all three trial were found more than 25 MPa, Similarly flexural strength and split tensile strength were found satisfactory. Author concluded light weight aggregate concrete made with cement mortar in combined use of fly ash with silica fume, has improved strength development in initial days of curing. Author recommended use of mix containing 40 % fly ash aggregates, 60 natural aggregates and 40 % cement replaced by 30 % fly ash+ 10 % silica fume for structural components. [Nazeer M. and Kumar R. A., 2014]55 prepared high-volume fly ash concrete blended with metakaolin. Fly ash used as partial replacement of cement in Portland cement concrete was 50% by weight. Metakaolin was used to replace the remaining cement by 5%, 10%, 15% and 20%. The concrete mix was formed for grade M30 with water binder ratio as 0.44 and two curing conditions i.e. boiling and normal curing were used. Test for determining workability, compressive strength, split tensile strength, modulus of elasticity and impact strength of concrete were carried out. It was observed that the impact resistance of concrete blended with fly ash and metakaolin was higher but compressive strength, tensile strength and modulus of elasticity was lower than that of controlled Polrtland cement concrete. [Patil et. al., 2015]56 evaluated the strength of high performance self-compacting concrete incorporated with a combination of fly ash and metakaolin. The fly ash was used in proportions of 5%, 15% and 25% and Metakaolin was used in proportions of 3%, 6% and 9%. The optimum percentages of metakaolin and fly ash for strength properties of concrete were found 9% and 15% respectively. [Muthupriya P. et. al., 2011]57 studied the behavior of high performance reinforced concrete column made with metakaolin and fly ash as a partial replacement of ordinary Portland cement. Concrete mixes were formed by using 10% fly ash and different percentages of metakaolin for long and short columns. Higher strength development and increased ductility were observed in concrete containing fly ash and metakaolin as compared to normal concrete mix. Metakaolin when used as 7.5 % by weight of concrete gave the maximum strength which was 12% higher than normal concrete. The brittleness of concrete was observed to be increased which causes sudden failure of columns with explosive sound. [Li G. and Zhao X., 2003]58 investigated the effect of combination of fly ash and granulated blast furnace slag in high strength concrete partially replacing the cement in it. It was observed that this combination can be used to improve early compressive strength. [Pratap K. V. et. al., 2014]59 observed that a concrete mix of M60 grade incorporated with fly ash and GGBS had a higher compressive strength, flexural strength and split tensile strength as compared to normal mix concrete. The compressive strength was found to be increased by 11.13%, flexural strength by 11.74% and split tensile strength by 23.01% at 28 days as well as long term properties of the concrete. [Ali S. A. and Abdullah S., 2013]60 partially replaced cement in concrete by fly ash and GGBS. Fly ash was added in percentages of 20%, 40% and 60% and GGBS was added in percentages ranging from 5 – 10%. The compressive strength, split tensile strength and flexural strength increased up to 40% of fly ash and 9 % of GGBS. Alaa M. Rashad et. al., 2014]62 conducted study to produce high volume fly ash concrete using portland cement silica fume, GGBS and Class F fly ash. Author found increase in compressive strength 5.8 % at 7 days of curing and 40 % at 28 days of curing. Further investigation shows that increase in dosage of silica fume from 10 and 20 % alongwith 50 % fly ash results in increment of compressive strength at all days of curing. The increases in compressive strengths for mix F70 were 107.6%, 191.4%, 127.4 % and 105.1 % at 7, 28, and 90 and 180 days of curing respectively. Author also found higher abrasion resistance of HVFA blended concrete found with silica fume and combination of silica fume and GGBS with class F fly ash. Lower abrasion resistance found with GGBS in HVFA concrete. [Jeong-Eun Kim et. al., 2016]63 conducted experimental study to investigate mechanical properties of energy efficient concrete with binary, ternary and quaternary admixture at different curing ages. Investigation showed use of silica fume increased the compressive strengths, splitting tensile strengths, modulus of elasticity and Poisson's ratios. On the other hand, the compressive strength and splitting tensile strength decreased with increasing fly ash. [Indu Lidoo et. al., 2017]64 prepared an experimental program to design high performance concrete M100 using mineral admixture alccofine 1203 and fly ash. Various combinations of trial mixes were prepared with alccofine and fly ash. Replacement percentage were 8%, 10%, 12%, 14% for alccofine and 10 % for fly ash. Author found lower the value of w/ binder ratio the higher is the compressive strength of concrete. 28 days compressive strength of concrete was found 89.2 MPa, 95MPa, 93 MPa, 90 MPa with alccofine 8 %, 10 %, 12 %, 14 % respectively at constant FA content 10%. Addition of 10 % silica fume provide better results. [S. Abbas et. al., 2016]65 studied various research papers and prepared a database on the material characterization of UHPC and its potential for large-scale field applicability. Investigation indicated fly ash improves compressive strength, elastic modulus, flexural strength and bond strength. Effect on UHPC under dynamic and impact loading was also found. Investigation shows that UHPC provides a viable and long-term solution for improved sustainable construction owing to its ultrahigh strength properties, improved fatigue behavior. The Author revealed that the curing regimes and fiber dosage are the main factors that control the mechanical properties of UHPC. [Srivastava V. et al, 2012]66 used a combination of silica fume and metakaolin in Portland cement concrete to study its effect on 7 and 28 day compressive strength. The optimum dose of silica fume and metakaolin for maximum compressive strength was 6% and 15% respectively. [Anbarasan A. and Venkatesan M., 2015]67 carried out compressive strength test, split tensile test on concrete made by silica fume and metakaolin as partial replacement of cement. The optimum percentage replacement of cement with silica fume and metakaolin is 35 % and 15 % respectively. At this percentage, the strength was observed to be higher than the conventional concrete. [Shirke A. H. et. al., 2014]68 studied the performance of concrete incorporating metakaolin, silica fume and a combination of them. Replacing cement by 5 % Silica fume and 15% metakaolin by weight gave the highest strength. [Shaikh, 2019]69 carried out study to investigate effects of supplementary cementitious materials fly ash, slag, silica fume, nano silica and ultra-fine fly ash for partial replacement of cement on mechanical properties of recycled coarse aggregate concrete. Various trial mixes were prepared and compared with control mixes. Firstly concrete containing 50 % recycled coarse aggregate for replacement of coarse aggregate and 50 % slag or fly ash for replacement of cement were prepared. Secondly 5%, 10% and 15% silica fume were added to previous mix. Thirdly, concrete containing 50 % recycled coarse aggregate, 2% nano silica and 10% ultrafine fly ash were prepared. Results were compared with control concrete containing 100% and 50% natural coarse aggregate. Water-to-binder ratios of all concrete were kept constant, however, superplasticizer was added in the mixes containing silica fume, nano silica and ultra-fine fly ash to improve the workability. Study reveals that addition of high volume fly ash and high volume slag reduces compressive strength whereas the reduction in high volume fly ash was more at all days of curing. The addition of silica fume is, however, recovered the compressive strength reduction of both high volume fly ash and slag concretes containing 50% RCA. The addition of nano silica and ultrafine fly ash also improved the compressive strength of recycled aggregate concrete. Author found similar results in case of indirect tensile strength. [Dale P. Bentz, 2014]71 conducted experimental program to study high volume fly ash concrete with limestone powder of 1.6 μm and 16 μm median particle size. Concrete were prepared using 10 % of both limestone powder with limestone aggregates and siliceous aggregates. It was investigated that 1.6 μm median particle size limestone powder provided an improved performance in comparison to 16 μm median particle size limestone powder. The physical and chemical interaction of limestone with the cement hydrates also likely contributes to the superior mechanical properties of concretes containing limestone aggregates in comparison to concrete using siliceous aggregates.

### 3.5 Durability properties of concrete containing mineral admixtures

[Bremseth S. K., 2010] 10 discussed the various advantages and disadvantages of using fly ash in concrete. The most important advantage of fly ash concrete is the ability to resist alkali aggregate reaction whereas the greatest disadvantage of using Fly ash in concrete is Air entraining. [Bargaheiser K. and Butalia T. S. 2007]11 reviewed the advantages of using high-volume fly ash concrete to resist corrosion damage in structures. Carbon dioxide and chloride penetrating the concrete are main reasons for corrosion of concrete. Use of Fly ash in concrete helps in reducing Carbon dioxide emission, provides sustainable design and longer service life of its infrastructure, slows down the ingress of moisture, oxygen, chlorides, Carbon Dioxide and aggressive chemicals in the concrete and prevents the deleterious effect of corrosion in reinforced concrete structures. [Sarath Chandra Kumar and Bendapudi P. Saha, 2011] 17 prepared detailed literature on contribution of high volume fly ash to the properties of mortar and concrete and found fly ash replacement of cement is effective for improving the resistance of concrete to sulfate attack expansion. . [T.P. Singh, 2007]16 shared experience in field performance of high volume fly ash concrete and found that HVFAC has superior permeability properties at higher curing days to conventional concrete. Therefore, it is a strongly viable sustainable building material in the years ahead. [Zaldiwar et.al., 2013]21 conducted research program to study the effect of grinding time on 10 %, 20% and 30% ground fly ash. SEM analysis showed increase in fineness of fly ash with ball milling treatment. BET surface area found greater with longer grinding time 5 hrs. [J. Hoppe Filho et. al. 2013]22 found high volume fly ash concrete containing 50 % fly ash and 20 % additional hydrated lime presented a lower accumulated charge density and coefficient of chloride diffusion than control concrete.

[Qiang Wang et. al., 2013]20 Incorporated blended steel slag super fine fly ash as mineral admixture in concrete and compared the performance with concrete containing ordinary fly ash. Result indicated Paste and concrete containing blended mineral admixture have smaller porosities than concrete containing ordinary fly ash. [Maeijer et. al., 2020]23 conducted experimental study to investigate the effect of two types ultrafine fly ash one with particle size d90 < 9.3 7 µm (FA1) second with d90 < 4.6 µm (FA2) for replacement of two types cement Portland cement and slag cement for concrete and mortar. Percentage replacement of cement for mortar were 0%, 15%, 25%, 35%, 50% and for concrete 0%, 15% , 25% for both type ultra-fine fly ash. Study reveals that incorporation of ultrafine fly ash (d90 < 4.6 µm) has positive influence on the resistivity, chloride migration coefficient and alkali-silica reaction (ASR) and negative influence on the carbonation resistance.[Obla et. al., 2003]24 investigated and compared properties of silica fume concrete and ultra-fine fly ash concrete. Study reveals that UFFA concrete shows higher resistance to rapid chloride permeability, almost equal resistance to electrical resistivity, chloride diffusivity, freezing and thawing than silica fume concrete but higher than the control concrete. [Faiz U.A. Shaikh and Steve W.M. Supit, 2015] 27 investigated the effect ultrafine fly ash on durability properties of concretes containing high volume class F fly ash as partial replacement of cement. Properties were measured at 28 and 90 days. Results show high volume fly ash concrete containing 32% fly ash and 8% ultra-fine fly ash exhibited superior durability properties. [Hu Jin et al., 2014]29 investigated properties of high strength concrete by replacing cement by super-fine fly ash (25%) and lime stone powder (10%) and found that high strength concrete containing super-fine FA and lime stone powder exhibit lower adiabatic temperature rise, a lower permeability and a larger carbonation depth.

[Roy D. K. S. and Sil A., 2012]31 investigated silica fume can also be used in construction places where chemical attack, frost action etc. are common. [Pradhan D. and Dutta D, 2013]34 found improved pore structures at the transition zone of silica fume concrete.

[Isfahani et. al., 2016]37 investigated durability properties of concrete using 0.5%, 1%, 1.5% nano silica for water/binder ratios 0.65, 0.55, and 0.5. Durability properties of concrete with different w/b ratios showed highly varying tendency by increasing NS dosage. The addition of 0.5% nano silica decreased the apparent chloride diffusion coefficient for w/b 0.65 and 0.55; however, higher nano silica dosages did not decrease it with respect to reference value. It was found that nano silica increases electrical resistivity, changes marginally sorptivity and water absorbtion. The carbonation coefficient was not noticeably affected by increasing nano silica dosages. [Zhuang and Chen, 2019]38 prepared a literature summary on influence of nano-$SiO_2$ on concrete properties and found remarkable improvement on effect of nano –$SiO_2$, especially in the aspect of enhancing the durability of concrete. [Andrade et al., 2020]40 studied the effect of nano-silica on the ternary system of rice husk ash, silica fume and Portland cement. It was reported that the quaternary mixtures containing nano-silica exhibited least mean pore diameter. The synergistic effect of nano-silica was reported to be beneficial in the quaternary system. Shashikumar and Keshavamurthy, 2019 ]4 carried out study to check the efficiency of high volume fly ash and nano silica in reducing the voids in concrete through wet packing density test. Firstly, optimum packing density of concrete containing 13%, 15%, 17%, 19%, 21% cement content with varying w/c ratios were determined. And secondly optimum packing density of concrete containing cement replacement by high volume fly ash for a particular w/c ratio were determined which produced maximum reduction in void ratio with 50 % high volume fly ash. Nano silica 1 % to 4 % were also added to the high volume fly ash concrete. The test indicated a positive outcome in terms of reduction in voids by high volume fly ash and nano silica to a large extent. [Liu et. al., 2020] Surface protection has been accepted as an effective way to improve the durability of concrete. In this study, nanosilica (NS) was used to improve the impermeability of cement-fly ash system and this kind of material was expected to be applied as surface protection material (SPM) for concrete. Binders composed of 70% cement and 30% fly ash (FA) were designed and nanosilica (NS, 0–4% of the binder) was added. Pore structure of the paste samples was evaluated by MIP and the fractal dimension of the pore structure was also discussed. Hydrates were investigated by XRD, SEM, and TG; the microstructure of hydrates was analyzed with SEM-EDS., e results showed that in the C-FA-NS system, NS accelerated the whole hydration of the cement-FA system. Cement hydration was accelerated by adding NS, and probably, the pozzolanic reaction of FA was slightly hastened because NS not only consumed calcium hydroxide by the pozzolanic reaction to induce the cement hydration but also acted as nucleation seed to induce the formation of C-S-H gel. NS obviously refined the pore structure, increased the complexity of the pore structure, and improved the microstructure, thereby significantly improving the impermeability of the cement-FA system. , is kind of materials would be expected to be used as SPM; the interface performance between SPM and matrix, such as shrinkage and bond strength, and how to cast it onto the surface of matrix should be carefully considered.

[Patil B. B. and Kumbhar P. D., 2012]5 investigated the effect of metakaolin on concrete for M60 grade. The concrete was subjected to chloride and sulphate attack and it was inferred that addition of metakaolin enhances the chemical resistance of concrete. In this particular research, the high reactivity metakaolin samples have silica and alumina content of 81%. It is considered that the high reactivity metakaolin has a high purity and high kaolinite content. As a result, 7.5% addition is sufficient to reduce the calcium hydroxide to the minimum level. [Badogiannis E. et. al., 2002]43 used two categories of metakaolin first produced metakaolin and second commercially available high purity metakaolin to replace cement in the concrete. It was observed that both metakaolin reduces chloride permeability, gas permeability, sorptivity and pore size when compared to ordinary Portland cement concrete. [Devi, 2015]44 used metakaolin from 5% to 20% as a partial replacement of cement and found corrosion resistance at all days of curing of concrete. Metakaolin is also found to react with calcium hydroxide which improves the pore structure of the concrete. [Babu and Kondraivendhan et. al., 2019]45 conducted experimental study to examine the effect of admixed chloride, sulphate and chloride-sulphate solutions on the corrosion performance of rebar of metakaolin and red mud blended concrete. The performance of the rebar was monitored by corrosion current density values using linear polarization resistance technique. The changes in electrical resistivity due to the presence of salts and different binder type reflects the corrosion behavior of rebar. The results indicated that the presence of magnesium sulphate increases the corrosion rate in both OPC and MK blended concrete. It was observed that once the corrosion initiated, the corrosion rate of rebar is high in concrete admixed with composite solution of chloride-sulphate ions than that of admixed with pure chlorides. The concrete blended with metakaolin performed better as compared to OPC concrete in terms of higher electrical resistivity and lower chloride induced corrosion current density with and without presence of sulphate ions.

[Ramezanianpour et. al. A. A., 2013]48 found concrete with 50% replacement of cement by GGBS showed an increase in resistance to sodium sulphate solution after 270 days where as concrete with 35% replacement levels show a decrease in resistance after 270 days of exposure. [Pavia E. and Condren S. 2008]50 examined the durability of GGBS concrete when exposed to silage effluent solution and magnesium sulfate solution properties like permeability, porosity, water absorption, capillary suction, compressive strength and mass loss were evaluated for different amounts of GGBS incorporated in the concrete. Author observed that the durability of concrete when subjected to silage effluent cycles and salt crystallization increases with the increase in GGBS content. There was a decrease in permeability, water absorption, capillary suction, mass loss and compressive strength loss in GGBS concrete exposed to silage effluent and salt cycling as compared to OPC concrete. Therefore, concrete mix with partial replacement of cement with GGBS can be efficiently used for agricultural use in silos.

### 3.6 Durability properties of concrete containing mineral admixture with fine and ultrafine materials

[Wongkeo W. et. al., 2014]53 evaluates the influence of high-calcium fly ash and silica fume on self-compacting concrete (SCC). The percentages of fly ash used ranges from 40 to 70% where as that of silica fume ranges from 0 to 10%. The optimum percentage of fly ash was found to be 40% when used with 10% silica fume at water-cement ration of 0.3. [Patil et. al., 2015]56 evaluated durability of high performance self-compacting concrete incorporated with a combination of fly ash and metakaolin. The fly ash was used in proportions of 5%, 15% and 25% and metakaolin was used in proportions of 3%, 6% and 9%. It was found that use of metakaolin and fly ash resulted in changes in the chemical composition of the pore solution phase of the hydrated material and increased the chloride resistance of concrete. The optimum percentages of metakaolin and fly ash for durability of concrete were found 9% and 15% respectively. [Muthupriya P. et. al., 2011]57 studied the behavior of high performance reinforced concrete column made with metakaolin and fly ash as a partial replacement of ordinary Portland cement. Concrete mixes were formed by using 10% fly ash and different percentages of metakaolin for long and short columns. Enhanced durability were observed in concrete containing fly ash and metakaolin as compared to normal concrete mix. **[**Tilo Proske et. al. ,2014]61 investigated the effect of mineral addition such as fly ash, GGBS and limestone powder on durability of concrete with low cement and water content. The carbonation depth of concretes with 150–175 kg/m$^3$ of cement was equal or lower than the depth of the conventional reference concretes for exterior structures. [S. Abbas et. al., 2016]65 studied various research papers and prepared a database on the material characterization of UHPC and its potential for large-scale field applicability. Investigation shows that UHPC provides a viable and long-term solution for improved sustainable construction owing to its very low porosity, leading to excellent resistance against aggressive environments. The Author revealed that the curing regimes and fiber dosage are the main factors that durability properties of UHPC. [Anbarasan A. and Venkatesan M., 2015]67 carried sorptivity test on concrete made by silica fume and metakaolin as partial replacement of cement. The optimum percentage replacement of cement with silica fume and metakaolin is 35 % and 15 % respectively. At this percentage, durability was observed to be higher than the conventional concrete. [Shirke A. H. et. al., 2014]68 studied the performance of concrete incorporating metakaolin, silica fume and a combination of them. Concrete which was ternary blended with metakaolin and silica fume showed the least mass loss on exposure to HCl solution.

## 4. CONCLUSIONS

The present study aimed at reviewing the literature on various mineral admixture used in concrete. These include effect of mineral admixtures such as fly ash, ultra-fine fly ash, silica fume, nano silica, metakaolin, ground granulated blast furnace slag on fresh, hardened and durability properties of concrete. The literature review revealed the following conclusions-

1. Fly ash increases workability, setting time, and reduces heat of hydration. Incorporation of fly ash in concrete results in increased compressive strength, tensile strength and flexural strength. It also increases resistance to alkali aggregate reactions, slows down ingress of moisture, oxygen, chloride, carbon dioxide and aggressive chemicals and prevents corrosion. The main disadvantages of using fly ash are lower rate of strength gain, increased air entraining and increased slump loss.

2. Ultra-fine fly ash increases slump, setting time, reactivity and reduces heat of hydration of concrete. Ultra -fine fly ash with fly ash exhibited superior durability properties such as chloride induced corrosion, water sorptivity, volume of permeable voids, chloride ion penetration, chloride diffusivity, electrical resistivity, alkali- silica reaction and porosity.

3. Addition of silica fume helps in increasing the strength of concrete by 10–15 % and also gives high early strength. Other advantages of adding silica fume are lower water-cement ratio, resistance to frost action and chemical effect. However, silica fume reduces workability of concrete and increases the consistency. Silica fume with fly ash content in concrete, increases compressive strength, water requirement for normal consistency decreases setting time and reduces workability but remained higher than that of Portland cement concrete.

4. Nano silica with high volume fly ash efficiently improves the strength. Nano silica reduces setting time, slump, and improves electrical resistivity shrinkage, sorptivity and water absorbtion. Nano silica addition shows good enhancement in the mechanical properties, nano silica with metakaolin produces concrete with a dense microstructure, which will decrease the voids in concrete.

5. Metakaolin increases the compressive strength up to 12 %, gives higher resistance to chemical effect, reduces chloride permeability, sorptivity and pore size and enhances corrosion resistance of concrete. The main disadvantage of using metakaolin as partial replacement of cement in concrete is that it reduces workability of concrete. Metakaolin with fly ash increases, workability, chloride resistance of concrete, increases compressive strength, tensile strength and modulus of elasticity. Metakaolin with silica fume increases strength, reduces slump loss, exposure to HCl solution.

6. Ground granulated blast furnace slag helps in increasing compressive strength, flexural strength and tensile strength up to 30%. Incorporation of GGBS in concrete increases workability, enhances sodium sulphate resistance, provides better durability against silage effluent cycles and salt crystallization, and decreases permeability, water absorption and capillary suction. However, GGBS slows down the setting time of concrete, which can cause delay in the construction process. GGBS and fly ash in combination increases compressive strength, flexural strength and split tensile strength. GGBS and silica fume in combination increases compressive strengths, splitting tensile strengths, modulus of elasticity, Poisson’s ratios, and abrasion resistance.

## REFRENCES

1. Park Y. S., Suh J. K., Lee J.H. and Shin Y.S. (1999), Cement and Concrete Research, Vol. 29 (1397).

2. Nehdi M. and Hayek M. (2005), Cement and Concrete Research, Vol. 35 (731).

3. J. Prabakar (2019), “Influence of nano silica and metakaolin admixed concretes of different grades on mechanical properties”, Indian Concrete Journal.

4. Shashikumar C.S. and M. Keshavamurthy (2019), "Influence of high volume fly ash and nano silica on particle packing of concrete", Indian Concrete Journal.

5. Patil B. B. and Kumbhar P. D. (2012), "Strength and durability properties of high performance concrete incorporating high reactivity metakaolin", International Journal of Modern Engineering Research (IJMER), Vol. 2 (3), pp 1099-1104.

6. K. A. Gruber, Terry Ramlochan, Andrea Boddy, R. D. Hooton and M. D. A. Thomas (2001), "Increasing concrete durability with high reactivity metakaolin", Cement & Concrete Composites, Vol. 23, pp. 479-484.

7. M. Thomas, R. D. Hooton, C. Rogers, and B. Fournier, "50 years old and still going strong" , Concrete International, vol. 34, p. 35, 2012.

8. A. Fulton and W. Marshall, "The use of fly ash and similar materials in concrete", in ICE ProceedIngs, pp. 714–730, 1956.

9. J. B. Newman, Advanced Concrete Technology: Constituent Materials, Butterworth-Heinemann, 2003.

10. R. F. Blanks, "The use of portland-pozzolan cement by the bureau of reclamation", in ACI Journal ProceedIngs, 1949.

11. ACI Committee 232, "Use of fly ash in concrete", Tech. Rep. ACI 232. 2R-03, 2003.

12. ACI Committee 363, "State of the art report on high-strength concrete", in ACI Journal Proceedings, 1984.

13. A. M. Neville and J. J. Brooks, Concrete Technology, Longman Scientific & Technical, 2010.

14. M. Loots, R. Snellings, A. Maul, L. Van den Abeele, Feasibility study report FLAME, 2017.

15. K. Boonen, K. Breemersch, I. Vanderreydt, VASH: Value Ash – screening LCA and LCC report, VITO, p. 29, 2018.

16. Properties of Concrete Containing Ultra-Fine Fly Ash by Karthik H. Obla, Russell L. Hill, Michael D. A. Thomas, Surali G. Shashiprakash, and Olga Perebatova, ACI Materials Journal, Vol. 100 (3), 2003.

17. Effect of ultra-fine fly ash on concrete performance and durability Patricia Kara De Maeijera*, Bart Craeyea,b , Ruben Snellingsc , Hadi Kazemi-Kamyabc , Michel Lootsd , Koen Janssense and Gert Nuytse, Construction and Building Materials, 2020, 263 (120493).

18. AnasAlKhatib, Mohammed Maslehuddin∗, Salah Uthman Al-Dulaijan (2020), "Development of high performance concrete using industrial waste materials and nano-silica", Journal of materials Research and Technology, vol. 9(3), pp. 6696-6711.

19. A. Shvarzman, K. Kovler, G. S. Grader and G. E. Shter,"The effect of dehydroxylation/amorphization degree on pozzolanic activity of kaolinite", Cement and Concrete Research, vol. 33, no. 3, pp. 405–416, 2003.

20. C. Bich, J. Ambroise, and J. Pera, "Influence of degree of ´ dehydroxylation on the pozzolanic activity of metakaolin" ,Applied Clay Science, vol. 44, no. 3-4, pp. 194–200, 2009.

21. E. Badogiannis, G. Kakali and S. Tsivilis, "Metakaolin as supplementary cementitious material: optimization of kaolin to metakaolin conversion", Journal of Thermal Analysis and Calorimetry, vol. 81, no. 2, pp. 457–462, 2005.

22. E. Guneyisi, M. Geso ¨ glu, T. ˘ Ozturan and K. Mermerdas ¨ , "Microstructural properties and pozzolanic activity of calcinedkaolins as supplementary cementing materials", Canadian Journal of Civil Engineering, vol. 39, no. 12, pp. 1274–1284, 2012.

23. H. Baioumy and A. R. Ibrahim, Mineralogical Variations among the Kaolin Deposits in Malaysia.

24. M. N. A. Saad, W. P. De Andrade and V. A. Paulon, "Properties of mass concrete containing an active pozzolan made from clay", Concrete International, vol. 4, pp. 59–65, 1982.

25. J. A. Larbi, The cement paste-aggregate interfacial zone in concrete [Ph.D. dissertation], TechnischeUniversiteit Delft, 1991.

26. M. A. Halliwell, "Preliminary assessment of the performance of portland cement concrete containing metakaolin", Tech. Rep. TCR48/92, BRE, 1992.

27. P. C. Hewlett, Ed., Lea's Chemistry of Cement and Concrete, Elsevier Science & Technology, 2004.

28. S. J. Martin, "The use of metakaolin in high strength concrete", Tech. Rep. Laboratory Report 78, RMC Readymix Limited, 1995.

29. S. Wild, J. M. Khatib, and A. Jones, "Relative strength, pozzolanic activity and cement hydration in superplasticised metakaolin concrete", Cement and Concrete Research, vol. 26, no. 10, pp. 1537–1544, 1996.

30. Patil S. L., Kale J. N. and Suman S. (2012), "Fly ash concrete: a technical analysis for compressive strength", International Journal of Advanced Engineering Research and Studies, Vol. 2, (1), pp. 128-129.

31. Wankhede P.R. and Fulhari V.A. (2014), "Fly ash in concrete - a literature study of the advantages and disadvantages", COIN project report, Number 18.

32. Bremseth S.K. (2010). "Effect of fly ash on properties of concrete", International Journal of Emerging Technology and Advanced Engineering, Vol. 4 (7), pp. 284-289.

33. Bargaheiser K. and Butalia T.S. (2007), "Prevention of corrosion in concrete using fly ash concrete mixes", Concrete Technology Forum, Dallas, Texas, pp. 1-16.

34. Yash Shrivastava and Ketan Bajaj (2012), "Performance of Fly Ash and High Volume Fly Ash Concrete in Pavement Design", IACSIT Coimbatore Conferences, IPCSIT vol. 28, Singapore.

35. P. Sravana and P. Srinivasa Rao, (2006)," Effect of Thermal Cycles on Compressive strength of High Volume Fly ash Concrete", 31st Conference on Our World in Concrete & Structures, Singapore.

36. Gunavant. Kate and Pranesh B. Murnal (2013), "Effect of Addition of Fly ash on shrinkage characteristics in high strength concrete", International Journal of Advanced Technology in Civil Engineering, Volume 2, Issue 1.

37. Soni D.K. and Saini J. (2014), "Mechanical Properties of High Volume Fly Ash (HVFA) and Concrete Subjected to Evaluated 1200C Temperature", International Journal of Civil Engineering Research, Vol. 5, Issue 3, pp. 241-248.

38. T. P. Singh (2007), "Field performance of high volume fly ash concrete",– The Indian Experience by, MCD Road Project, New Delhi.

39. Sarath Chandra Kumar, Bendapudi and P. Saha, (2011) "Contribution of Fly ash to the properties of Mortar and Concrete", International Journal of Earth Sciences and Engineering, Volume 04, pp 1017-1023.

40. VanitaAggrawal, S. M. Gupta and S. N. Sachdeva, (2010), "Concrete Durability through High Volume Fly ash Concrete (HVFC) A Literature review", International Journal of Engineering Science and Technology Vol. 2(9), 4473-4477.

41. Rafat Siddiue, (2013), "Properties of fine aggregate-replaced high volume class F fly ash concrete", Leonardo Journal of science, Vol. 22 pp 79-90.

42. Zaldiwar Cadena A. A., Diaz-Pena I., Gonzalez-lopez J. R. Vazquez-Acosta F., Cruz-Lopez A., Vazquez-Cuchillo O., Vazquez-Rodriguez F. and Serrato-Arias L. M. (2013)," Effect of milling time on mechanical properties of fly ash incorporated cement mortars", Advance Material Research, Vol. 787 pp 286-290, Switzerland.

43. J. Hoppe Filho, M. H. F. Medeiros, E Pereira, P Helene M. ASCE and G. C. Isaia, (2013) "High volume fly ash concrete with and without hydrated lime: Chloride diffusion coefficient from accelerated test", ASCE Journal of Materials in Civil Engineering vol. 25 pp 411-418.

44.Qiang Wang, Peiyu and Rengguang Liu (2013), "Effect of Steel Slag-Super Fine Fly Mineral Admixture ash and Ordinary Fly ash on the properties of concrete", Material Science Forum, Vol. 743-744 pp 926-930, Switzerland.

45. Maeijer, Bart Craeyea b , Ruben Snellingsc , Hadi Kazemi-Kamyabc , Michel Lootsd , Koen Janssense, Patricia Kara De and Gert Nuytse, (2020), "Effect of ultra-fine fly ash on concrete performance and durability" Construction and Building Materials, 2020, Vol. 263 (120493).

46. Karthik H. Obla, Russell L. Hill, Michael D. A. Thomas, Surali G. Shashiprakash, and Olga Perebatova (2003), " Properties of Concrete Containing Ultra-Fine Fly Ash", ACI Materials Journal, pp. 426-433.

47. Luigi Coppola, Denny Coffetti and Elena Crotti, (2018) "Plain and Ultrafine Fly Ashes Mortars for Environmentally Friendly Construction Materials", Journal Sustainability.

48. R. Roychand, S. De Silva, D. Law and S. Setunge (2016), "Micro and Nano Engineered High Volume Ultrafine Fly Ash Cement Composite with and without Additives", International Journal of Concrete Structures and Materials, Vol., 10, pp. 113-124.

49. FaizU.A.Shaikh and Steve W.M.Supit (2015), "Compressive strength and durability properties of high volume fly ash (HVFA) concretes containing ultrafine fly ash (UFFA)",construction and building material, volume 82, pp 192-205.

50. L. Krishnaraj and P.T. Ravichandran, (2020) "Characterisation of ultra-fine fly ash as sustainable cementitious material for masonry construction".

51.Hu Jin, Li Mengyuan, (2014) "The properties of high strength concrete containing super-fine fly ash and lime stone powder", Applied Mechanics and Materials, Vol. 477-478 pp 926-930, Switzerland.

52. Ghutke V.S. and Bhandari P.S. (2014), "Influence of silica fume on concrete", IOSR Journal of mechanical and civil engineering (IOSR-JMCE), pp. 44-47.

53. Roy D.K.S. and Sil A. (2012), "Effect of partial replacement of cement by silica fume on hardened concrete", International journal of emerging technology and advanced engineering, Vol. 2, Issue 8, pp. 472-475.

54. Srivastava V., Harison A., Mehta P.K., Atul and Kumar R. (2013), "Effect of Silica Fume in Concrete", International Journal of Innovative Research in Science, Engineering and Technology, Vol. 3, Issue 4, pp. 254-259.

55. Amudhavalli N.K. and Mathew J. (2012), "Effect of silica fume on strength and durability parameters of concrete", International journal of engineering sciences & emerging technologies, Vol. 3, Issue 1, pp. 28-35.

56. Pradhan D. and Dutta D. (2013), "Effects of Silica Fume in Conventional Concrete", International Journal of Engineering Research and Applications, Vol. 3, Issue 5, pp. 1307-1310.

57. Shanmugapriya T. and Uma R.N. (2013), "Experimental Investigation on Silica Fume as partial Replacement of Cement in High Performance Concrete", The International Journal Of Engineering And Science (IJES), Vol. 2, Issue 5, pp. 40-45.

58. Forood Torabian Isfahani,1 Elena Redaelli,1 Federica Lollini,1 Weiwen Li,2 and Luca Bertolini (2016), "Effects of Nanosilica on Compressive Strength and Durability Properties of Concrete with Different Water to Binder Ratios", Advances in Materials Science and Engineering.

59. ChenglongZhuang and Yu Chen (2019), " The effect of nano-SiO2 on concrete properties A review", Nanotechnol Rev Vol. 8, 562–572.

60. Seifan M, Mendoza S, Berenjian A (2020), "Mechanical properties and durability performance of fly ash based mortar containing nano- and micro-silica additives", Construction Building Material Vol.252 ,(August):11912.

61. da Silva Andrade D, da Silva Rêgo JH, Rojas MF, Morais PC, de Souza Serafim MJ and Lopes AN 2020, "Properties of ternary cement pastes with nanosilica and rice husk ash", ACI Mater J Vol.117(1):233–42.

62. Madhusudanan S, Amirtham LR, Nallusamy S (2019), "Symbiotic outcomes of potency and microstrure on nano composite with microsilica and nanosilica additives", J Nano Res Vol. 57:105–16.

63. Huaqing Liu,1 Yan Zhang,1 Ruiming Tong,1 Zhaoqing Zhu,1 and Yang Lv 2 (2020), " Effect of Nanosilica on Impermeability of Cement-Fly Ash System", Hindawi Advances in Civil Engineering Volume 2020.

64. Suryawanshi Y.R., Kadam A.G., Ghogare S.S., Ingale R.G. and Patil P.L. (2015), "Experimental Study on Compressive Strength of Concrete by Using Metakaolin", International Research Journal of Engineering and Technology (IRJET), Vol. 2, Issue 2, pp. 235-239

65. Badogiannis E., Tsivilis S., Papadakis V. and Chainiotakis E. (2002), "The effect of metakaolin on concrete properties", International congress: Challenges of concrete construction, Dundee, Scotland, In Innovations and Developments in Concrete Materials and Construction, pp. 1-9

66. Devi M. (2015), "Implication of metakaolin in quarry dust concrete", International journal of structural and civil engineering Research, Vol. 4, Issue 2, pp. 171-174.

67. U. Raghu Babu, B. Kondraivendhan (2019), "Impact of sulphate on chloride-induced corrosion of steel in concrete",Indian Concrete Journal.

68. Awasare V. and Nagendra M.V. (2014), "Analysis of strength characteristics of GGBS concrete", International Journal of Advanced Engineering Technology, Vol. 5, Issue 2, pp. 82-84.

69. Arivalagan S. (2014), "Sustainable studies on concrete with GGBS as a replacement material in cement", Jordan journal of civil engineering, Vol. 8, Issue 3, pp. 263-270.

70. Ramezanianpour A.A., Atarodi S. and Sami M. (2013), "Durability of concretes containing ground granulated blast furnace GGBS against sulfate attack", Third international conference on sustainable construction materials and technologies.

71. Tamilarasan V.S., Perumal P. and Maheswaran J. (2012), "Workability studies on concrete with GGBS as a replacement material for cement with and without superplasticiser", International journal of advanced research in engineering and technology (IJARET), Vol. 3, Issue 2, pp. 11-21.

72. Pavia S. and Condren E. (2008), "Study of the durability of OPC versus GGBS concrete on exposure to silage effluent", Journal of materials in civil engineering, Vol. 20, Issue 4, pp. 313-320.

73. Mohamed H.A. (2011), "Effect of fly ash and silica fume on compressive strength of self-compacting concrete under different curing conditions", Ain shams engineering journal, Vol. 2, pp. 79-86.

74. Nochaiya T., Wongkeo W. and Chaipanich A. (2010), "Utilization of fly ash with silica fume and properties of Portland cement–fly ash–silica fume concrete", Fuel 89, pp. 768-774.

75. Wongkeo W., Thongsanitgarn P, Ngamjarurojana A. and Chaipanich A. (2014), "Compressive strength and chloride resistance of self-compacting concrete containing high level fly ash and silica fume", Materials and design 64, pp. 261-269.

76. S. Lokesh, M. G. Ranjith Kumar, S. Loganathan (2013), "Effective Utilization of High Volume Fly ash with Light Weight Aggregate in Concrete for Construction Industry", International Journal of Advanced Structures and Geotechnical Engineering, Vol. 02, No. 04.

77. Nazeer M. and Kumar R.A. (2014), "Strength Studies on Metakaolin Blended High-Volume Fly Ash Concrete", International Journal of Engineering and Advanced Technology, Vol. 3, Issue 6, pp. 176-179.

78. Patil S., Mahalingasharma S.J., Prakash P. and Jawali V. (2015), "Characteristics of high performance self-compacting concrete incorporating fly-ash and metakaolin", International Journal of Research in Engineering and Technology, Vol. 4, Issue 6, pp. 264-269.

79. Muthupriya P., Subramanian K. and Vishnuram B.G. (2011), "Investigation on behaviour of high performance reinforced concrete columns with metakaolin and fly ash as admixture", International Journal of Advanced Engineering Technology, Vol. 2, Issue 1, pp. 190-2.

80. Li G. and Zhao X. (2003), "Properties of concrete incorporating fly ash and ground granulated blast-furnace slag", Cement and concrete composites, Vol. 25, Issue 3, pp. 293-299.

81. Pratap K.V., Bhasker M. and Teja P.S.S.R. (2014), "Triple Blending of Cement Concrete With Fly Ash and Ground Granulated Blast Furnace Slag", International Journal of Education and applied research, Vol. 4, Issue 2, pp. 54- 58.

82. Ali S.A. and Abdullah S. (2014), "Experimental study on partial replacement of cement by fly ash and GGBS", International journal for scientific research and development, Vol. 2, Issue 7, pp. 304-308.

83. TiloProske, Stefan Hainer, MoienRezvani and Carl-Alexander Graubner, (2014) "Eco-friendly concretes with reduced water and cement content – Mix design principles and application in practice", Volume 67, pp 413-421.

84. Alaa M. Rashad, Hosam El-Din H. Seleem, and Amr F. Shaheen, (2014) "Effect of Silica Fume and Slag on Compressive Strength and Abrasion Resistance of HVFA Concrete", International Journal of Concrete Structures and Materials Vol.8, No.1, pp.69–81.

85. Jeong-Eun Kim, Wan-Shin Park, Young-Il Jang, Sun-Woo Kim, Sun-Woong Kim, Yi-Hyun Nam, Do-Gyeum Kim, and KeitetsuRokugo, (2016) "Mechanical Properties of Energy Efficient Concretes Made with Binary, Ternary, and Quaternary Cementitious Blends of Fly Ash, Blast Furnace Slag, and Silica Fume", International Journal of Concrete Structures and Materials, Volume 10, Number 3, pp.S97–S108.

86. InduLidoo, Sanjeev Naval, Rajeev Sharda, (2017) "Design of High Performance Concrete (HPC) M100 Using Mineral Admixture (Alccofine 1203) and Fly Ash", International Interdisciplinary Conference on Science Technology Engineering Management Pharmacy and Humanities, Singapore.

87. S. Abbas, M. L. Nehdi, and M. A. Saleem, (2016) "Ultra-High Performance Concrete: Mechanical Performance, Durability, Sustainability and Implementation Challenges", International Journal of Concrete Structures and Materials Vol.10, No.3, pp.271–295.

88. Srivastava V., Kumar R., Agarwal V.C. and Mehta P.K. (2012), "Effect of silica fume and metakaolin combination on concrete", International journal of civil and structural engineering, Vol. 2, Issue 3, pp. 893-900.

89. Anbarasan A. and Venkatesan M. (2015), "Strength characteristics and durability characteristics of silica fume and metakaolin based concrete", International journal of innovations in engineering and technology (IJIET), Vol. 5, Issue 1, pp. 1-7.

90. Shirke A.H., Sengupta A.A. and Bhandari P.K. (2014), "Performance characteristics of blended cement", International journal of innovative research in science, engineering and technology.

91. Faiz Uddin Ahmed Shaikh (2019), "Effects of SCMs and nano- and ultrafine-materials on mechanical properties and carbon footprint of recycled aggregate concretes", Indian Concrete Journal.

93. Dale P. Bentz, Taijiro Sato, Igor de la Varga, and W. Jason Weiss, (2012) "Fine limestone additions to regulate setting in high volume fly ash mixtures", Cement & Concrete Composites, 34 pp11-17.

94. Dale P. Bentz, Ahmad Ardani, Tim Barrett, Scott Z. Jones, Didier Lootens, Max A. Peltz, Taijiro Sato, Paul E. Stutzman, JussaraTanesi , and W. Jason Weiss, (2014) "Multi-Scale Investigation of the Performance of Limestone in Concrete", Construction and Building Materials, 2014.

95. Imène Joudi-Bahri, A. Lecomte, Taoufik Achour (2012), "Use of limestone sands and fillers in concrete without superplasticizer", Materials Science, Cement & Concrete Composites.