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Incorporation of Mineral Admixtures in Sustainable High Performance Concrete

Nima Farzadnia[1]*, Abang Abdullah Abang Ali[1] and Ramazan Demirboga [1, 2]

[1]Housing Research Centre, University Putra Malaysia, 43400, Serdang, Selangor.
[2] Ataturk University, Engineering Faculty, Civil Engineering Dept., 25240, Erzumum, Turkey.

*Corresponding Email: n_farzadnia@yahoo.com

ABSTRACT

Concrete is a widely used construction material around the world, and its properties have been undergoing changes through technological advancement. Numerous types of concrete have been developed to enhance the different properties of concrete. So far, this development can be divided into four stages. The earliest is the traditional normal strength concrete which is composed of only four constituent materials, which are cement, water, fine and coarse aggregates. With a fast population growth and a higher demand for housing and infrastructure, accompanied by recent developments in civil engineering, such as high-rise buildings and long-span bridges, higher compressive strength concrete was needed. At the beginning, reducing the water-cement ratio was the easiest way to achieve the high compressive strength. Thereafter, the fifth ingredient, a water reducing agent or super plasticizer, was indispensable. However, sometimes the compressive strength was not as important as some other properties, such as low permeability, durability and workability. Thus, high performance concrete was proposed and widely studied at the end of the last century. Currently, high-performance concrete is used in massive volumes due to its technical and economic advantages. Such materials are characterized by improved mechanical and durability properties resulting from the use of chemical and mineral admixtures as well as specialized production processes. This paper reviews the incorporation of mineral admixtures in binary, ternary and quaternary blended mortars in concrete.

Keywords: *High performance concrete, Sustainability, Mineral admixtures. Incorporation*

**Corresponding Author*

1.0 INTRODUCTION

It has been a long time that the human being has been dealing with two basic needs; food and shelter. He has been coping with nature to overcome his problems using the special talent of his, the power of thought. With the emergence of technology, fulfilling his dreams created a boom in his quality of life; from wooden shelters to high rise concrete buildings and from very simple house design to making some impossible constructions possible. All this filled the human being with pride and glory and made him ignore his appreciation for nature. Gradually, he was surrounded by different environmental problems such as global warming, deforestation, land fills, toxic chemical wastes, industrial by products and so on.

Recently, one of the main concerns of most countries is coming up with a low impact material to be used in construction which can meet the needs and desires of both contractors and consumers and at the same time fulfill the principles of a new but fast growing trend; sustainable development.

1.1 Concrete

Considering the volume, concrete is the first mostly used building material in the world. Every year more than 1 m^3 is produced per person (more than 10 billion tons) worldwide [1]. The easily transformed cement into functional shape makes concrete so popular in construction industry. Furthermore it is a low cost, low energy material made from the most widely available elements on earth. If properly designed and produced, concrete has excellent mechanical and durability properties. It is moldable, adaptable, and relatively fire resistant. Perhaps, its most tempting quality is the fact that it is an engineered material, which means it can be engineered to satisfy almost any reasonable set of performance specifications, more than any other material currently available.

All advantages of concrete have been strong incentives for scientists to explore new research and applications. So far, this development can be divided into four stages. The first is the traditional normal strength concrete (NSC). Usually, concrete is composed of only four kinds of materials, which are cement, water, fine aggregates and coarse aggregates. With population growth and an increase in housing need, which is accompanied by development of civil engineering, such as high-rise buildings and long-span bridges, higher compressive strength concrete is needed. When the compressive strength of concrete is higher than 50 MPa, it is usually defined as high strength concrete (HSC) [2]. At the very beginning, reducing the water-cement ratio was the easiest way to reach high compressive strength. Therefore, in HSC, the fifth ingredient, a water reducing agent or super plasticizer, is inevitable. However, sometimes the compressive strength is not considered as important and necessary as some other properties, such as low permeability, fine durability and excellent workability. Thus, high performance concrete (HPC) was proposed and widely studied at the end of the last century.

HPC is used in massive volumes due to its technical and economical advantages. Such materials, so called the 21st century concrete, are distinguished by enhanced mechanical and durability properties due to use of chemical and mineral admixtures as well as specialized production processes[3-6].

1.2 Sustainability as the Core Motive for Innovation

Although concrete has been serving human beings to provide amenities, the service comes with a significant price. Regarding the immense amount of concrete production annually, it has considerable impacts on the environment. Consumption of vast amount of natural resources, release of almost one ton of carbon dioxide into the atmosphere from the production of each ton of Portland cement is two major environmental issues. Worldwide, the cement industry alone is estimated to be responsible for about 7% of all CO2 generated [7].Moreover, regardless of water supply shortages in most parts of the world, the production of concrete requires large amounts of water. Finally, the demolition and need of disposal of concrete structures, pavements, etc., creates another environmental burden. Construction and demolition debris produces a considerable fraction of solid waste in developed countries.

What is listed above indicates that concrete has become the victim of its own achievements but for sure it is still one of the most practical building material in the world. The challenges that this industry is facing are more a result of Portland cement production. So, the most effective remedy to solve the problem is to use less Portland cement which means to replace as much Portland cement as possible by supplementary cementitious materials, especially those that are byproducts of industrial processes, and to use recycled materials in place of natural resources. Different efforts have been made to reduce the drawbacks of concrete on environment such as replacement of aggregates and binders. It is believed that the adverse effect of cement, co2 emission, may be minimized if mineral admixtures are applied; as they reduce cement consumption, energy and cost. In eco cement, large amounts of Portland cement clinker (up to 70%) are replaced by available mineral additives such as natural pozzolanic materials, sand, limestone, granulated blast furnace slag, fly ash, glass cullet and ceramic waste [8].A case study by G.C.Isaia (2000) reveals that a reduction of up to 67% of the energy requirements and 80% in the cementing materials cost may be expected when pozzolan additions of up to 50% are used. With 25% of pozzolans added, energy requirements may drop by 33% and cost by 20% [9]. This review paper focuses on mineral admixtures used as supplementary cementitous materials in order to reduce Portland cement production.

2.0 MINERAL ADMIXTURES

In the literature, different types of mineral admixtures in forms of binary, ternary or quaternary blended mortars have been used. The effect of different minerals such as fly ash(FA), lime stone, stone waste powder, slag (steel, lead, copper) , silica fume(SF), metakaolin(MK), carbon black, rice husk ash(RHA) and sand stone on different mechanical properties has been taken into consideration. Burak Felekoglu (2007) conducted a research to investigate the application of a quarry dust limestone powder in self-compacting paste and concrete. Results showed that utilizing high volumes of quarry waste limestone powder is possible to produce economical normal-strength self compacting concrete(SCC) [10]. G. Hüsken et al (2008) studied the application of fine stone waste materials in the form of premixed sand. He suggested the usage of stone waste materials to reduce the manufacturing cost by cutting down the amount of the most cost intensive materials in earth-moist concrete mixes, binder and filler, by means of an optimized particle packing [11]. B. Sioulas et al (2000) explored the use of slag-blended cements in the production of high-strength concrete. The result indicated a considerable reduction in net temperature rise and thermal gradient due to the application of slag replacement in HSCs [12]. Metakaolin was another mineral admixture which was assessed by Anand Kuber Parande et al (2008). They tested the mechanical property and corrosion behavior of carbon steel using MK (5–20%) as partial replacement in ordinary Portland cement. Compressive strength, resistivity, ultra pulse velocity, open circuit potential, water absorption and weight loss were studied. It was reported that up to 15% replacement of metakaolin in OPC improves the mechanical properties of concrete. Corrosion of carbon steel is also improved by the addition of metakaolin up to 15% [13].

Sewage sludge ash (SSA) is another admixture that experts showed interest in. Martin Cyr et al (2007) conducted a study on the physical, chemical and mineralogical characteristics of SSA and the evaluation of its use in cement-based materials. The results convinced that the mortar demands significant high water usage due to its irregular grains having a high specific surface area [14].

Some local pozzolans in different parts of the world raised the question of whether they are appropriate enough to be used as a replacement to cement. G. Fajardo et al (2009) examined the use of natural pozzolans as a partial substitute of normal Portland cement in reinforced mortar specimens. It was reported that for the same cover depth, the use of pozzolans resulted in a remarkable increase in mortar resistivity and corrosion initiation time, and as a result, the rate of corrosion of rebars was decreased after corrosion initiation [15].

Among all mineral admixtures, fly ash has attracted the most attention. J.M. Miranda et al (2005) explored the question of whether activated fly ash cement can protect the reinforced steel as effectively as Portland cement. It was proved that activated fly ash mortars improves the passivity in reinforcing steel as rapidly and effectively as Portland cement mortars and the durability issue is guaranteed[16]. Velu Saraswathy et al (2007) also investigated corrosion characteristics of three kinds of cements, namely ordinary Portland cement, Pozzolana Portland cement (PPC) and 25% fly ash replaced in ordinary Portland cement FA mixes under accelerated exposure conditions. The results suggested that PPC and FA replaced concrete higher corrosion resistance properties comparing with Ordinary Portland cement concrete in both cracked and uncracked samples [17].

However, corrosion is not the only durability issue affected by incorporation of fly ash. K.K. Sideris et al (2006) implemented an experimental investigation on the sulfate resistance and carbonation of plain and blended cement mortars containing Megalopoli fly ash (MFA) , Ptolemaida treated fly ash (PFA) and two natural pozzolans. The results showed that Ptolemaida treated fly ash (PFA) blended cements gave the lowest carbonation rate. Results indicated that obtaining sulfate resistant concrete structures with almost equal compressive strength is possible by using 50% PFA blended cements instead of Portland cement [18].

Incorporation of super plasticizers and fly ash was another approach in HPC. Jian Yin et al (2002) conducted tests on high-performance concrete containing ultra pulverized fly ash composite (PFAC) and super plasticizer. The results proved that the double effects of PFAC and super plasticizer enhances concrete performance in terms of excellent workability, lower drying shrinkage, better durability and higher mechanical properties [19]. Fineness of fly ash, as a leading factor in quality development of concrete came into consideration by Li Yijin et al. He investigated the effect of fineness and replacement levels of fly ash on the fluidity of cement paste, mortar, and concrete. The incorporation of ultra fine fly ash may increase the setting time of cement paste, slump and also decrease the water demand ratio due to its fineness [20].

Some more innovative efforts were made by other scientists in terms of fly ash blended mortars. Erdogan Ozbay et al (2009) applied Taguchi's experiment design methodology for optimal design of FA. The results revealed that 30% (of the weight) FA optimizes water permeability and water absorption, and 15% of FA enhances splitting tensile strength and compressive strength in SCC [21]. D.G. Snelson et al (2009) applied fly ash in concrete containig tire as partial replacement for coarse aggregates. Results proved the fact that, at all levels, the strength development with PFA was lower than that control samples. However, at long curing periods, low PC replacement levels of 10% are likely to show increased strength, relative to the PC control. But the incorporation of tire and FA was not suggested in the building industry [22].

Silica fume is another widely used mineral admixture. Incorporation of silica fume decreases permeability in concrete cover which leads to longer service life and durability of high performance concrete. Shin-ichi Igarashi et al (2005) reported that concrete samples containing silica fume with a water/binder ratio of 0.25 had larger amounts of fine pores in comparison with concretes without silica fume. This can explain the aoutogenous shrinkage at early ages in samples containing silica fume [23]. Also, M.J. Shannag (2000) explored the combination of silica fume and natural pozzolans (volcanic tuffs from Tal Rimah region of northeastern Jordan). Some tests were conducted for workability, density, compressive strength, splitting tensile strength, and modulus of elasticity. The results of this study elaborate that mixture of certain natural pozzolan and silica fume can enhance the compressive and splitting tensile strengths, workability, and elastic modulus of concretes, more than natural pozzolan and silica fume alone. The study suggested 15% silica of cement weight to achieve the highest strength [24]. P.S. Kumar et al (2007) studied the effect of silica fume on high performance reinforced concrete (HPRC) made with crushed sandstone coarse and fine aggregate together. The results showed that the incorporation of silica fume improved the flexural stiffness of HPRC beams and resulted in adequate safety factors against flexural failure [25]. In terms of the workability of high performance concrete, M. Mazloom et al (2004) implemented experimental work on short- and long-term mechanical properties of high-strength concrete containing different amounts of silica fume. The results of this research indicated that as the proportion of silica fume increases, short-term mechanical properties such as 28-day compressive strength are improved although there is a decrease in the workability of concrete. Also the level of silica fume replacement did not have a remarkable influence on total shrinkage; however, as the amount of silica fume increases, the autogenous shrinkage of concrete increases. At the same time, at higher level of silica fume replacements the basic creep of concrete decreases [26].

Not only industrial byproducts but also agro-wastes seemed to be efficient to improve concrete performance as well as its sustainability. Among agro-waste ashes, rice husk ash has been proved to be very functional. Deepa G Nair (2008) stated that RHA is the favorable sample to be used as pozzolanic cement additive [27]. Moreover, Alireza Naji Givi et al (2010) investigated the compressive strength, water permeability and workability of concrete by partial replacement of cement with agro-waste rice husk ash and the results indicated a higher compressive strength at 90 days at optimal replacement of 10%. Furthermore, a reduction in percentage of water absorption, velocity of water absorption and also coefficient of water absorption at all ages with ultra fine RHA particles was reported [28]. Graciela Giaccio et al (2007) studied the effects of rice husk ash in concrete based on analysis of mechanical behavior. The results revealed that the addition of RHA increases compressive strength especially in lower w/b ratio concretes but, at the same time, there is a tendency for more brittle failure mechanisms [29]. Furthermore, Qingge Feng et al (2004) reported a significant increase in hydration of cement [30].

The other agro-waste ash which is widely used is palm oil fuel ash. Weerachart Tangchirapat et al (2007) used palm oil fuel ash in concrete and the properties of concrete, such as setting time, compressive strength, and expansion due to magnesium sulfate attack, were investigated. The results reported delays in both initial and final setting time of concrete, while the compressive strength of samples with 20% replacement of POFA was increased. The results recognizes POFA as a new pozzolan for cement replacement in concrete, which is cost effective, reduces environmental problems, and the landfill area required for the disposal of POFA [31].

Efficient performance of agro waste ashes encouraged scientists to explore new agricultural ashes. K. Ganesan et al (2007) used another agro waste ash, sugarcane bagasse, as a pozzolanic material for the development of blended cements. Compressive strength, splitting tensile strength, water absorption, permeability characteristics, chloride diffusion and resistance to chloride ion penetration were investigated and BA was proved to be an effective mineral admixture. Twenty percent replacement was reported to be optimal [32].

2.1 Most Efficient Mineral Admixtures

Mineral admixtures have not been successful at all times. Ilker Bekir Topçu et al (2009) reported that the utilization of the waste marble dust in self-compacting concrete, as the filler material decreased the mechanical properties of hardened SCC [33]. To optimize the mechanical properties and improve durability issues in concrete industry, different tests were conducted to compare properties of various types of admixtures. Among all fly ash, silica fume, rice husk ash, lime stone proved to be more useful.

V. Bindiganavile et al (2001) investigated the effect of size and shape of mineral admixtures on the rebound and mechanical properties of shotcrete. Fly ash, silica fume, metakaolin and carbon black with different particle size gradations and shapes were compared. The result indicated that the particle size is more important than its shape. It was also proved that silica fume is superior to metakaolin due to its ultra fine particle size but a blend of silica fume and metakaolin achieves better properties [34].

Nezar R. Jarrah et al (1995) studied the effect of silica fume, fly ash and blast furnace slag cement on corrosion time initiation and corrosion rate. The study revealed the fact that the performance of silica fume blended cement, in terms of longer time to corrosion initiation and lower corrosion rate, is superior and it elongates the service life of reinforced concrete structures in chloride sulfate environments [35]. The performance of 15 reinforced concrete mixtures in a mixed magnesium-sodium sulfate environment was also assessed by Omar Saeed Baghabra Al-Amoudi (1995). Silica fume showed the best performance with regard to corrosion protection, while samples with fly ash and ground granulated blast-furnace slag (GGBS) exhibited an advanced degree of deterioration due to both sulfate attack and reinforcement corrosion [36]. Limestone filler and fly ash were studied by Eva Mnahoncakova et al (2007) in terms of water vapor diffusion coefficient, water absorption coefficient, water permeability, thermal conductivity, compressive strength and freeze resistance properties of two self-compacting concretes.The results indicate that limestone filler leads to faster hardening but after 90 days the strength values in both materials are almost the same. SCC with limestone has faster liquid water transport and heat transport whereas the water vapor transport is faster in the material containing fly ash which results in better freeze resistance [37]. The other test on permeability compared the performance of rice husk ash and silica fume. M.H. Zhang et al (1996) explored the incorporation of rice-husk ash in cement paste and concrete on the hydration and the microstructure of the interfacial zone between the aggregate and paste. The porosity in the interfacial zone of the rice-husk ash composite was reported to be higher than that of the silica fume composite [38].

M. Fauzi and M. Zain et al (2001) investigated the effects of mineral and chemical admixtures, and quarry dust on the physical properties of freshly mixed high performance concrete. They studied the incorporation of fly ash and silica fume with air trainers and super plasticizers in different samples. The results revealed that Silica fume in company with super plasticizer produces higher slump and slump flow than fly ash in fresh concrete mixes [39].

2.2 Ternary, Quaternary Blended Mortars

Different mineral admixtures can improve different properties of concrete. To replace cement in high volumes, scientists explored the incorporation of mineral admixtures in ternary and quaternary blended mortars on mechanical properties, durability, workability, cost effectiveness etc. Moncef Nehdi et al (1996) investigated the effect of limestone micro filler replacement of cement on the mechanical properties performance and cost effectiveness of low w/c ratio in super plasticized Portland cement mortars. It was reported that the most cost effective cement mortars was was achived with triple blended binder containing 10% silica fume and 10 to 15 % limestone. The study showed that [40].

J. Zelić et al was another scientist who conducted some experimental tests to explore the effect of incorporation of silica fume and limestone filler (LF) on pore size distribution, micro morphology, and compressive strength and sulfate resistance in both sodium and magnesium sulfate solutions. It was found that SF-blends obtain higher compressive strengths than LF-blends for the same replacement of cement. Incorporation of SF with LF improves compressive strength and shows a lower expansion than a control, more sulfate-resisting behavior, independent of the type of sulfate solutions, due to pore size refinement microstructure of mortars [41].

The mixture of silica fume and fly ash was another effort to enhance the performance of concrete. R.P. Khatri et al (1995) under took a study to compare mechanical properties as well as fresh concrete properties of concretes containing silica fume, fly ash and general Portland cement. The experiments showed that the mixture of silica fume and general Portland decreases the setting times but increases the superplasticizer demand for similar workability. Other advantages mentioned were improved compressive strength and lowered creep. Long term drying shrinkage was lower than the concrete containing GP only. Although the addition of fly ash into concrete containing GP cement and silica fume caused the early age strength to decrease, the strain due to drying shrinkage and creep increased [42].

Fly ash and ground granulated blast furnace slag were also used to improve the amount of cement replacement. Yazıcı et al (2009) implemented some experiments on reactive powder concrete using FA and GGBFS to study its mechanical properties (compressive strength, flexural strength, and toughness) under different curing conditions (standard, autoclave and steam curing). Test results revealed the fact that compressive strength of Reactive Powder Concrete (RPC) increased considerably after steam and autoclaving compared to the standard curing, while they decreased the flexural strength and toughness. But application of the GGBFS and/or FA improved the toughness of RPC under all curing regimes considerably [43]. Yu-Wen Liu (2006) applied fly ash and slag in low cement high performance concrete to form the top layer of a check dam to take advantage of the low hydration heat in concrete. The results revealed that the binding forces between cement paste and aggregates was strengthen due to the dense constituents and enhanced its ability to resist erosion attacks [44]. In another study on mixture of fly ash and slag, Ozkan Sengul et al (2009) replaced 50% of cement by finely ground fly ash and finely ground granulated blast furnace slag in concrete with water/binder ratios of 0.60 and 0.38 and tested rapid chloride permeability. The result indicated that incorporation of pozzolans are more effective than decreasing the water/cement ratio in rapid chloride permeability [45].

Having exploited rice husk ash in concrete, incorporation of RHA with FA was tested by P. Chindaprasirt et al (2008). He studied the strength, porosity and corrosion resistance of mortars containing ternary blends of ordinary Portland cement, RHA and FA. The result showed that the use of ternary blend of OPC, RHA and FA enhances the concrete in terms of strength at the low replacement level and at the later age. The chloride induced corrosion resistance is significantly improved by usage of FA and RHA. The results indicated that RHA is more effective than FA [46]. He also studied incorporation of Palm oil fly ash (POFA) to improve the quality of ternary blended mortars to decrease the Portland cement consumption. He conducted research to study the resistance to chloride penetration of blended Portland cement mortar containing POFA, RHA and FA. It was revealed that partial replacement of Portland cement with mentioned admixtures enhance the resistance to chloride penetration. RHA is found to be the most effective pozzolan followed by POFA and FA. The use of FA reduces the amount of superplastisizers (SP) required to maintain the mortar flow, while the incorporations of POA and RHA require more SP. The use of a blend of equal weight portion of POFA and FA, or RHA and FA produces mixes with good strength and resistance to chloride penetration. He also researched the effects of carbon dioxide on chloride penetration and chloride ion diffusion coefficient of blended Portland cement mortar containing POFA, RHA and FA. The test results reveal that RHA, POFA and FA enhance the performance of mortar in chloride ingress situations. RHA is a very effective pozzolan and is followed by POFA and FA, respectively. The application of pozzolan reduces the calcium hydroxide and the pH level of mortar. Carbon dioxide has an accumulative effect so the mortar is susceptible to chloride attack, thus lowers the resistance to chloride penetration. Mortars with RHA show the best performance in term of chloride penetration resistance. FA and POFA and the blend of these pozzolans produce mortars with reduced resistance to chloride penetration as a result of exposure to carbon dioxide [47].

Combination of blast furnace slag and metakaolin or silica fume is another approach in fulfillment of a low impact concrete. Zongjin Li et al (2003) chose the combination of metakaolin and slag and implemented research on the physical and mechanical properties of Portland cement (PC) containing metakaolin or a combination of MK and slag and its effect on the amount of super plasticizers used in concrete. The result of this study indicates that the incorporation of 10% MK and 20% or 30% ultra-fine slag together into PC, not only improved the fluidity of blended cements, but also the 28-day compressive strength of the cements was enhanced [48]. The damage caused by chemical attack on high strength concrete mixtures prepared with silica fume and blast furnace slag also was assessed by I brahim Turkmen (2008). It was reported that the optimum results were obtained from the 10% SF jointed with 5% GGBFS, prepared at 0.30 water-binder ratio and cured in lime-saturated water for 120 days[49].

Some scientists applied more than two supplementary cementitous materials to enhance the quality of binder in order to use less Portland cement. M. Nehdi et al (2004) choose class F fly ash, a ground granulated blast furnace slag, silica fume and rice husk ash (RHA) to explore durability of quaternary cements. The results indicate that high-volume replacement SCC made with quaternary cements can have dramatically lower chloride ion penetrability compared with SCC made with 100% OPC [50].

Wei Sun et al (2004) Studied quaternary blends of FA, slag and SF and the effect on porosity and corrosion in the so called green high performance concrete(GHPC). A reduction in the pH values of binder paste due to combination of mineral admixtures was reported, whereas the final pH values were still above the critical breakage pH values of passivation film on the steel bar surface. Also, the electrical resistance of concrete, with the exception of incorporation of silica fume and fly ash, was increased which might lead to a delay the initial corrosion time of steel bars and a decrease in the corrosion rate. At the same time, the results of electrochemistry and immerging–drying cycle tests indicated that silica fume incorporating in ternary or quaternary blended samples possessed a superior resistance to the steel corrosion in GHPC [51].

Yunsheng Zhang et al (2002) considered heat reduction important in concrete mixture of fly ash, slag and silica fume and the reduction of super plasticizers. The addition of mineral cementitious components reduced the 3-day hydration heat and also retarded the time of hydration temperature of the binder paste in HPC, which was especially true to double and triple-adding approaches[52]. Bing Chen et al (2008) implemented researches on light weight concrete to observe the effect of FA, slag and SF on workability. The results revealed the fact that mineral admixtures combinations provided better improvement of both the rheological and strength properties of light-weight concrete than any single mineral admixture type [53]. Erhan Güneyisi et al (2010) targeted shrinkage of HPC with FA, SF, slag and MK. It was shown that quaternary blended binder has accumulative effect on HPC while there was a marked reduction in the compressive strength of the concretes with increasing FA content and use of SF appeared to be the most effective mineral admixture on the drying shrinkage. The samples containing SF and MK had consistently higher compressive strength than the control concrete [54]. Radin Sumadi et al (2010) added more variety of minerals such as RHA and POFA to FA and SF and slag and monitored the effect of mixture on porosity, permeability, chemical agents and compressive strength of multi blended cement concrete (MBC). It was found that the strength of multi blended cement concrete at early age, on average, were 20% lower than control mortars, and at final age both were almost the same. However, the MBC system produced a low permeability mortar compared to control mortars. It was also reported that after exposure to chemical attack, the MBC mortar shows better resistance. With efficient curing the MBC mortar was higher in durability than control mortars when subjected to chemical attack [55].

Optimization of mineral admixtures is another approach which has been studied. Yanzhou Peng et al (2009) optimized the amount of FA, slag and SF to achieve an acceptable compressive strength. The optimal contents for ultra fine FA, slag and SF are reported as 10%, 17% and 15% by weight, respectively [56].

3.0 CONCLUSION

This paper reviews the incorporation of different mineral admixtures due to their properties, in order to enhance the quality of concrete as well as decrease its harmful impact on the environment.

- Each mineral such as silica fume, fly ash, rice husk ash, metakaolin, blast furnace slag, palm oil fuel ash, etc. can play a part to improve the performance of concrete. Since each mineral has one or two useful characteristics in binder blends, incorporations of two or three supplementary cementitous materials have been explored by different experts, and different properties such as early age or late hardening, compressive strength, tensile strength, dry shrinkage, creep, etc. have been studied.
- In the last decade, durability has been an important issue for all stock holders in the concrete industry. So, different tests on permeability, passivity and corrosion, chemical diffusion such as chloride ingress, sulfate attack and carbonation have been implemented on multi blended cement concrete.
- Still there are niches in the literature to explore. More mineral admixtures, whether industrial by products or agro-waste minerals, should be taken into consideration. Incorporation of more mineral and chemical admixtures might enable the concrete industry to reduce or even substitute General Portland cement which could lead to cleaner and less energy consuming, low impact building materials in the future.
- Nanoparticles can be applied to enhance the density of mixtures as well as increase the hydration of cementitous materials.
- Still, more tests should be run in order to prove the quality of concrete containing high volume supplementary cementitous material. Brittle behavior, crack formation, shrinkage, corrosion time initiation, passivity, carbon dioxide absorption, etc. are still question marks in the multi blended cement concrete field.

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5.0 REFERENCES

[1] Scrivener, Karen L. Innovation in use and research on cementitious material. Cement and Concrete Research , (2008) , pp 128–136.
[2] Xiao, Jianzhuang. Wedge splitting test on fracture behaviour of ultra high strength concrete. Construction and Building Materials , (2004), pp 359–365.
[3] Aitcin P.-C., and Neville A.M. igh-Performance Concrete Demystified. Concrete International15 , (1993),pp 21-26.
[4] Neiqian, F. High-Performance Concrete. China Construction Industry . (1996).
[5] W, Forster Stephen. High-Performance Concrete Stretching the Paradigm. Concrete International 16 , (1995), pp 33-34.

[6] Zhongwei, W. Green High-Performance Concrete: The Trend of Concrete. China Concrete and Cement Products , (1998), pp 3-6.
[7] Meyer, C. The greening of the concrete industry. Cement & Concrete Composites 31 , (2009), pp 601–605.
[8] K. Sobolev, I. Flores and R. Hermosillo. Nanomaterials and Nanotechnology for High performance concrete .Proceedings of ACI Session on "Nanotechnology of Concrete: Recent Developments and Future Perspectives , (2006, November 7), pp 91-118.
[9] Isaia, G. C. High-performance concrete for sustainable constructions. Waste Materials in Construction , (2000), pp 344-354.
[10] Felekoglu, Burak. Utilisation of high volumes of limestone. Resources, Conservation and Recycling 51 , (2007), pp 770–791.
[11] G. Hüsken and H.J.H. Brouwers. A new mix design concept for earth-moist concrete: A theoretical and experimental study. Cement and Concrete Research 38 , (2008), pp 1246–1259.
[12] B. Sioulas, J.G. Sanjayan. Hydration temperatures in large high-strength concrete columns. Cement and Concrete Research 30 , (2000), pp1791-1799.
[13] Anand Kuber Parande, B. Ramesh Babu, M. Aswin Karthik. Study on strength and corrosion performance for steel embedded. Construction and Building Materials 22 , (2008), pp 127–134.
[14] Martin Cyr, Marie Coutand, Pierre Clastres. Technological and environmental behavior of sewage sludge ash. Cement and Concrete Research 37 , (2007), pp 1278–1289.
[15] G. Fajardo, P. Valdez, J. Pacheco. Corrosion of steel rebar embedded in natural pozzolan based mortars exposed. Construction and Building Materials 23 , (2009), pp 768–774.
[16] J.M Miranda, A. Ferna ´ndez-Jime ´nez , J.A. Gonza ´lez , A. Palomo. Corrosion resistance in activated fly ash mortars. Cement and Concrete Research 35 , (2005), pp1210– 1217.
[17] Velu Saraswathy, Ha-Won Song. Evaluation of corrosion resistance of Portland pozzolana cement and. Materials Chemistry and Physics 104 , (2007), pp 356–361.
[18] K.K. Sideris, A.E. Savva, J. Papayianni. Sulfate resistance and carbonation of plain and blended cements. Cement & Concrete Composites 28 , (2006), pp 47–56.
[19] Jian Yin, Shiqiong Zhou, Youjun Xie, Yu Chen, Qinlian Yan. investigation on compounding and application of C80–C100. cement and Concrete Research 32 , (2002), pp 173–177.
[20] Li Yijin, Zhou Shiqiong, Yin Jian, and Gao Yingli. THE EFFECT OF FLY ASH ON THE FLUIDITY of concrete. Central South University, PRC .
[21] Erdog ˘an Ozbay, , Ahmet Oztas, Adil Baykasoglu, Hakan Ozbebek. Investigating mix proportions of high strength self compacting concrete by using Taguchi method. Construction and Building Materials 23 , (2009), pp 694–702.
[22] D.G. Snelson J.M. Kinuthia, P.A. Davies, S.-R. Chang. Sustainable construction: Composite use of tyres and ash in concrete. Waste Management 29 , (2009), pp 360–367.
[23] Shin-ichi Igarashi, A. W. Evaluation of capillary pore size characteristics in high-strength concrete at early ages. Cement and Concrete Research 35 , (2005), pp 513– 519.
[24] Shannag, M.J. High strength concrete containing natural pozzolan and silica fume. Cement & Concrete Composites 22 , (2000), pp 399-406.
[25] P.S. Kumar, M.A. Mannan, V.J. Kurian, H. Achuytha. nvestigation on the flexural behaviour of high-performance reinforced concrete beams using sandstone aggregates. Building and Environment 42 , (2007), pp 2622–2629.
[26] M. Mazloom a, A.A. Ramezanianpour, J.J. Brooks. Effect of silica fume on mechanical properties of high-strength concrete. Cement & Concrete Composites 26 , (2004) , pp347–357.
[27] Deepa G Nair, Alex Fraaij, Adri A.K. Klaassen,Arno P.M. Kentgens. A structural investigation relating to the pozzolanic activity of rice husk ashes. Cement and Concrete Research 38 , (2008), pp 861–869.
[28] Alireza Naji Givi, Suraya Abdul Rashid, Farah Nora A. Aziz, Mohamad Amran Mohd Salleh. Assessment of the effects of rice husk ash particle size on strength, water permeability and workability of binary blended concrete. Construction and Building Materials . (2010), in the press.
[29] Graciela Giaccio, Gemma Rodrı ´guez de Sensale, Rau ´ l Zerbino. Failure mechanism of normal and high-strength concrete with rice-husk ash. Cement & Concrete Composites 29 , (2007), pp 566–574.
[30] Qingge Feng, H. Yamamichi, M. Shoya, S. Sugita. Study on the pozzolanic properties of rice husk ash by hydrochloric acid pretreatment. Cement and Concrete Research 34 , (2004), pp 521–526.
[31] Weerachart Tangchirapat, Tirasit Saeting, Chai Jaturapitakkul,Kraiwood Kiattikomol, Anek Siripanichgorn. Use of waste ash from palm oil industry in concrete. Waste Management 27 , (2007), pp 81–88.

[32] K. Ganesan, K. Rajagopal, K. Thangavel. Evaluation of bagasse ash as supplementary cementitious material. Cement & Concrete Composites 29 , (2007), pp 515–524.
[33] ilker Bekir Topçu, Turhan Bilir, Tayfun Uygunog ˘lu. Effect of waste marble dust content as filler on properties of self-compacting concrete. Construction and Building Materials 23 , (2009), pp 1947–1953.
[34] V.Bindiganavile, N.banthia. fiber reinforced dry mix shotcrete with metakaolin. cement and concrete composite23 , (2001), pp 503-524.
[35] Nezar R. Jarrah, Omar Saeed Baghabra Al-Amoudi, Mohammed Maslehuddin",Oluwatoyin A. Ashiru and Abdulaziz lbrahim Al-Mana. Electrochemical behaviour of steel in plain and blended cement concretes in sulphate and/or chloride environments. Construction and Building Materials, Vol. 9, No. 2 , (1995), pp 97-103.
[36] Al-Amoudi, Omar Saeed Baghabra. Performance of 15 reinforced concrete mixtures n magnesium-sodium sulphate environments. Construction and Building Motrriuh Vol. 9. No. 3 , (1995), pp 149-158.
[37] Eva Mn ˇahonc ˇa ´kova ´, Milena Pavlı ´kova ´, Stefania Grzeszczyk, Pavla Rovnanı ´kovaRobert C ˇ erny ´. Hydric, thermal and mechanical properties of self-compacting concrete containing different fillers. Construction and Building Materials 22 , (2008), pp 1594–1600.
[38] M.H. Zhang, R. Lastra,V.M. Malhotra. RICE-HUSK ASH PASTE AND CONCRETE: SOME ASPECTS OF HYDRATION AND THE MICROSTRUCTURE OF THE INTERFACIAL ZONE BETWEEN THE AGGREGATE AND PASTE. Cement and Concrete Research, Vol. 26, No. 6 , (1996), pp 963-977.
[39] M. Fauzi M. Zain l, M. S. INFLUENCE OF ADMIXTURES AND QUARRY DUST ON THE PHYSICAL PROPERTIES OF FRESHLY MIXED HIGH PERFORMANCE CONCRETE . Structural Engineering, Mechanics and Computation (Vol. 2) . (2001).
[40] Moncef Nehdi, Sidney Mindess. OPTIMIZATION OF HIGH STRENGTH LIMESTONE FILLER CEMENT MORTARS. Cement and Concrete Research, Vol. 26, No. 6 , (1996), pp 883-893.
[41] J. Zelić, D. Jozić, and D. Krpan-Lisica. Synergistic Action of a Ternary System of Portland Cement – Limestone – Silica Fume in Concrete. Faculty of Chemical Technology, University of Split, Split, Croatia .
[42] R.P. Khatri and V. Sirivivatnanon, EFFECT OF DIFFERENT SUPPLEMENTARY CEMENTITIOUS MATERIALS ON MECHANICAL PROPERTIES OF HIGH PERFORMANCE CONCRETE. Cement end Concrete Research, Vol. 25, No. 1 , (1995), pp 209-220.
[43] Halit Yazıcı, Mert Yücel Yardımcı, Serdar Aydın, Anıl S . Karabulu. Mechanical properties of reactive powder concrete containing mineral admixtures under different curing regimes. Construction and Building Materials 23 , (2009), pp 1223–1231.
[44] Yu-Wen Liu a, Tsong Yen,Tsao-Hua Hsu,Jenq-Chuan Liou. Erosive resistibility of low cement high performance concrete. Construction and Building Materials 20 , (2006), pp 128–133.
[45] Ozkan Sengul, Mehmet Ali Tasdemir. Compressive Strength and Rapid Chloride Permeability of Concretes with Ground Fly Ash and Slag. american society of civil engineers . (2009).
[46] P. Chindaprasirt, S. Rukzon. Strength, porosity and corrosion resistance of ternary blend Portland cement, rice husk ash and fly ash mortar. Construction and Building Materials 22 , (2008), pp 1601–1606.
[47] P. Chindaprasirt, S. Rukzon,V. Sirivivatnanon. Resistance to chloride penetration of blended Portland cement mortar containing palm oil fuel ash, rice husk ash and fly ash. Construction and Building Materials 22 , (2008), pp 932–938.
[48] Zongjin Li, Zhu Ding. Property improvement of Portland cement by incorporating with metakaolin and slag. Cement and Concrete Research 33 , (2003), pp 579–584.
[49] I ˙brahim Turkmen, Ru stam Gul,Cafer C - elik. A Taguchi approach for investigation of some physical properties of concrete produced from mineral admixtures. Building and Environment 43 , (2008), pp 1127–1137.
[50] M. Nehdi, M. PardhanS. Koshowski. Durability of self-consolidating concrete incorporating high-volume replacement composite cements. Cement and Concrete Research 34 , (2004), pp 2103– 2112.
[51] Wei Sun, Yunsheng Zhang, Sifeng Liu, Yanmei Zhang. The influence of mineral admixtures on resistance to corrosion of steel bars in green high-performance concrete. Cement and Concrete Research 34 , (2004), pp 1781–1785.
[52] Yunsheng Zhang, Wei Sun, Sifeng Liu. Study on the hydration heat of binder paste in high-performance concrete. Cement and Concrete Research 32 , (2002), pp 1483–1488.
[53] Bing Chen, Juanyu Liu. Experimental application of mineral admixtures in lightweight concrete with high strength and workability. Construction and Building Materials 22 , (2008), pp 655–659.

[54] Erhan Güneyisi, Mehmet Gesog ˘lu, Erdog ˘an Özbay. Strength and drying shrinkage properties of self-compacting concretes incorporating multi-system blended mineral admixtures. Construction and Building Materials 24 , (2010), pp 1878–1887.
[55] Sumadi, Radin. multi blended cement concrete. malaysia: projectwork. (2010).
[56] Yanzhou Penga, Shuguang Hub, Qingjun Ding. Dense packing properties of mineral admixtures in cementitious material. Particuology 7 , (2009), pp 399–402.