

Review

Incorporation of metakaolin and nanosilica in blended cement mortar and concrete- A review

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ABSTRACT

The construction industries are focusing on the use of innovative, cost efficient and ecofriendly materials in infrastructural development. In view of this, there is need to search for alternative construction materials that can be used in place of the conventional normal concrete. There have been numerous materials that could be used as supplementary cementitious materials in concrete thereby making it sustainable and durable. Some of these materials are naturally occurring or byproducts of agro-based or manufacturing industries, and as well as agricultural wastes. Metakaolin being obtained from naturally occurring kaolin clay had been extensively used in place of cement in mortar/concrete making but much attentions have not been given towards considering the effect of the source of the clay on its reactivity properties as well as effect of factory blending approach of MK and clinker. Also, the delay in strength attainment of pozzolan blended concrete calls for incorporation of innovative materials that will enhance the development of strength at early stages. Nanoparticles are innovative construction materials obtained from green plants or chemical and have been shown to enhance the development of mechanical properties of mortar and concrete at low age of curing with enhancement in microstructural arrangement. There is need to explore more of the green method of synthesis as recent researches are tailored towards the reduction/eradication of greenhouse gases that could deplete the ozone layer. This article focuses on previous researches that have been carried out to investigate the effect of MK and nanosilica on the properties of mortar and concrete.

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1. Introduction

Cement are finely ground materials obtained from oxides of lime with tendencies of holding different minerals into compact form (Neville, 2011). Portland cement being one of the most important constituents of composite concrete has been reported to be amongst the mostly used materials in the developing countries. The global production rate in a year is approximately 1.2 billion tonnes (Coutinho, 2003). This huge application of the conventional binder (cement) had resulted into its paucity and consequently, increase in its price, thereby posing a major problem towards the construction of effective housing scheme in Nigeria as price of materials takes about 67% of the cost of building construction (Olusola and Adesanya, 2004; Ayangade et al., 2004). In terms of production, Ordinary Portland Cement (OPC) has relative abundance amongst other forms of cement and hence, it constitutes high emission of carbon dioxides and other forms of greenhouse gases thus depleting the ozone layer. In addition, cement undergoes hydration thereby form calcium silicate hydrate as well as calcium hydroxide (lime). The free lime has tendency of causing expansion in concrete thereby making the concrete prone to untimely failure and inhibiting its durability properties (Anbarasan and Venkatesan, 2015). There has been advocates for the development of sustainable and environmental pollution free alternative binding materials as against the conventional OPC. Reports have shown that OPC is the highest source of carbon dioxide emission. Hence, some industrial wastes and naturally occurring clay have been opined to exhibit supplementary cementitious properties (Weerdt et al., 2011; Yesiyurt, 2018). Asides from the environmental disadvantages emanating from the production of OPC, there is need to sourced for alternative local materials that could complement the binding tendency of cement. This exponential increase in the price of OPC could be reduced by replacing cement either partially or fully with supplementary cementitious materials (Coutinho, 2003). According to JingHao-Liang et al. (2021) the clinker of OPC could be inter-ground with roasted clay and powder of limestone to produce blended cement at lower cost with minimal environmental pollution. Blended cements are hydraulic cements consisting essentially of an intimate and uniform blend of Portland cement and one or more inorganic materials which could either be agricultural wastes or industrial by-products like fly ash (FA), rice husk ash, silica fume (SF), calcined clay, ground granulated blast furnace slag, meta-kaolin, etc (ACI 116, 2000). They are obtained by intergrinding ordinary Portland cement clinker with supplementary cementitious materials (SCM). SCMs are by-products from other processes or natural materials. Blended cements have been shown to have both technical and environmental benefits. They influence the characteristics of hardened concrete via hydraulic or pozzolanic activity. SCMs are either used as admixture or additive either partly or fully in the production of high strength and impermeable concrete or mortar (PCA, 2018). Several researchers had worked on the use of SCMs as partial replacement for cement in mortar and concrete (Raheem and Ikotun, 2020; Raheem and Ige, 2019; Imran and Anwar Khan, 2018; Raheem and Kareem, 2017).

According to Rafat and Juvas (2009) SCMs are part of production of durable and high strength concrete. They are naturally occurring materials, industrial wastes, or byproducts of agro-industries amongst are fly ash (FA), Silica Fume (SF), Granulated Blast Furnace Slag (GGBS), Rice Husk Ash (RHA) and Metakaolin (MK). MK has the ability of reaction with lime produced from the hydration of cement thereby forming additional calcium silicate hydrate (CSH) (El-Diadamony et al. 2018). Cements and other SCM being one of the constituents of concrete have significant roles to play most especially in the area of mechanical properties of the concrete due to reactions occurring at both micro and nano level.

On this note, the application of nanoparticles has the tendency of improving on the structural arrangement of molecules of concrete and consequently, enhancing the materials properties (Tawfiq et al., 2019).

Nanomaterial is gaining more attention in terms of drives towards the development of innovative constructions materials due to its small size, high surface area to volume and high resistance again wear and corrosion (Sharma et al., 2018). Its significance cannot be overemphasized as it has the capability of producing concrete with very high strength, reduction in the consumption of conventional portland cement with consequent reduction in environmental pollution and attainment of desired concrete strength within short period of curing ages (Morsy et al., 2011). The advantages of using nanomaterial in concrete technology are so enormous amongst are: it acts as activator thereby enhancing the reactivity of pozzolans, improves hydration of cement and early strength development of concrete and mortar, enhancement in both compressive and flexural strengths of concrete, it helps refines pores in concrete thereby reducing the penetration of chloride and other chemicals consequently; preventing steel corrosion, reduction in the degree of carbonization, enhancement of strength of concrete at its weakest zone which is the interface between the cement matrix and aggregates, reduction in size of Calcium Hydroxide $[Ca(OH)_2]$ and increase in formation of tropism in concrete (Chenglong and Yu, 2019; Mohammad and Saeed, 2012; Khaloo et al., 2016). The prospects of these particles in the field of construction have resulted to searching for very simple methods of synthesizing through plants and microbes that are non-toxic, low energy consumption as well as pressure and consequently becomes environmentally friendly to the ecosystem (Lateef et al., 2016; Salem et al., 2014). These particles have greatly influenced the designing and construction pattern of civil engineering structures in numerous ways and amongst are emergence of very light weight and strong concrete composite, self-cleansing of surfaces of materials, better heat and fire resistance, waterproof properties, good cementitious and durability properties (Gajanan and Tijare, 2018). Furthermore, the applications of these particles in the construction Industries have been on the increase due to its environmental benefits in the sense that it greatly reduces the rate of environmental pollution with consequent reduction of energy consumption emanating from the production of some conventional binding materials, tendency of coating surfaces with thin films as well as aiding the corrosion resistance of steel (Zhu et al., 2004). According to Gajanan and Tijare (2018), the application of nanoparticles in concrete technology has been favorable in the sense that its conventional constituents are macro materials whose properties could be thoroughly investigated on a nano scale thereby giving more insight as to how its strength and durability properties could be enhanced. For instance, the conventional particle size of cement could be adjusted to give nano cement which when incorporated with carbon nano tubes (CNT) produces smart concrete. However, despite the outlined benefits attached to the application of nanoparticles in concrete, the high surface area of the particles results to their ineffective dispersion in cement matrix and problem of ductility (Jo et al., 2007; Li et al., 2004; Li et al., 2006; Qing et al., 2007).

Nanomaterials are very small sized materials having the tendency of influencing the properties of concrete in terms of mechanical and microstructural properties (Sanchez and Sobolev, 2010). The small size of the particle denotes high surface area to volume and hence, has the tendency of speeding up the rate of hydration of cement and consequently, the pozzolanic reaction (Mahender and Ashbok, 2017). Asides from the environmental benefits of nanoparticles, the addition of nanoparticles can improve structural efficiency, durability, and strength of cementitious

thereby enhancing the quality and life span of the structures (Monica and Andrew, 2013).

1.1. Kaolin and metakaolin

Kaolin is a fine, white naturally occurring grained rock with kaolinite as the dominating mineral constituents rich in hydrated aluminium silicate. The whitish colour could be due to the minimal content of iron and some impurities therein (Zegeye et al., 2013; Oscar et al. 2016). Murray (2007) reported that kaolinite has hexagonal shape and pseudo flaky in nature with earthy fracture pattern having relative abundance of silica, alumina and water as thus: 46.54, 39.50 and 12.96% respectively. According to RMRDC (2008) Kaolin is a clay of hydrous aluminosilicates mineral found in some of the states of Nigeria and has been estimated to be around 3 billion metric tonnes. The states include: Ekiti, Kogi, Katsina, Ogun, Edo, Plateau, Nassarawa, Abia, Kano, Oyo, Niger, Delta, Bauchi, Sokoto, Kaduna, and Borno. The clay is of four classes depending on the constituent minerals: nacrite, halloysite, dickite, and kaolinite. It comprises additional minerals amongst are: quartz, mica, illite, halloysite, attapulgite, feldspar, bauxite, rutile, silliminate (Olokede et al. 2010; Adamis et al. 2005). Metakaolin is a class N pozzolan that exhibits supplementary cementitious materials and it is produced from the dehydroxylation of kaolin clay in the range of 500–800 °C (Kadri et al., 2011). The clay often undergoes a heat treatment process with the tendency of rupturing the long-range order of alumina and silica layer thereby forming an amorphous aluminosilicate to produce metakaolin (Sabrah et al., 2014; Countertop Concrete Institute, 2007). The temperature is in the range of 700–900 °C relatively lower than 1450 °C as applicable in the production of cement; with corresponding reduction in energy consumption and CO₂ emission and hence, reducing environmental pollution (Glavind, 2009). In order to improve the calcination process, there could be pretreatment of the clay using HCl before the application of heat so as to improve its physico-chemical, mineralogical and morphological properties San et al. (2009). Lenarda et al. (2007) pretreated kaolin with H₂SO₄ at 90 °C prior to roasting at 850 °C and it was observed that the roasted clay obtained possessed high surface area and enhanced catalytic tendency.

1.2. Properties of metakaolin

Metakaolin is a class N pozzolan with the ability of reacting with lime with the availability of water thereby showing tendency of binding loose materials together (ASTM C618, 2001). The XRD of MK as obtained in the work of El-Diadamony et al. (2018) shown in Fig. 1 and Fig. 2 revealed quartz to have the peak intensity of counts and this simply implies high quantity of silica present in the MK and consequently, determines the pozzolanicity of the MK. In addition, the work of Menshaz et al. (2017) opined that even when the raw kaolin clay is not calcined, the predominant mineral is quartz which depicts enormous amount of silica therein. The chemical composition of MK has great influence on its reactivity and silica have been found to be the most predominant compounds available in calcined kaolin on many occasions as obtained by some researchers are contained in Table 1. The area of attention of concrete production is its properties both in fresh and hardened state which in turns is greatly dependent on types and properties of concrete constituent, methods of production, time amongst others. MK differs mainly from most other pozzolanic materials due to its high reactivity with lime, and its ability to speed up the hydration reaction (Justice and Kurtis, 2007). The silica and alumina contained in pozzolan has the tendency of reacting with lime produced during hydration of cement in the presence of water thereby forming cementitious products calcium silicate hydrates and calcium aluminate hydrates (Adesanya and Raheem, 2009).

The microstructural arrangement of MK as reported in the work of Al-Jabri and Shoukry (2018) is presented in Fig. 3 revealed that the thickness is less than 20 on a nanometer scale and shape of structure is in form of plate with high length to thickness ratio. In addition, the length and breadth could as well fall in the range of 200–500 nm. The plate like nature of the SEM micrograph is in agreement with the result of Ghasan et al. (2018). MK has good prospects in the making of high strength concrete because of its silica content thus making it exhibits SCM properties (Zongjin and Zhu, 2003). Ding et al. (1997) opined that MK reduces time required for the formation of colloids in concrete and consequently, enhancing strength development. Concrete has been found to be prone to shrinkage in the plastic state and the infusion of MK had enhanced shrinkage reduction and inhibit the formation of cracks (Tazawa and Miyazawa, 1995).

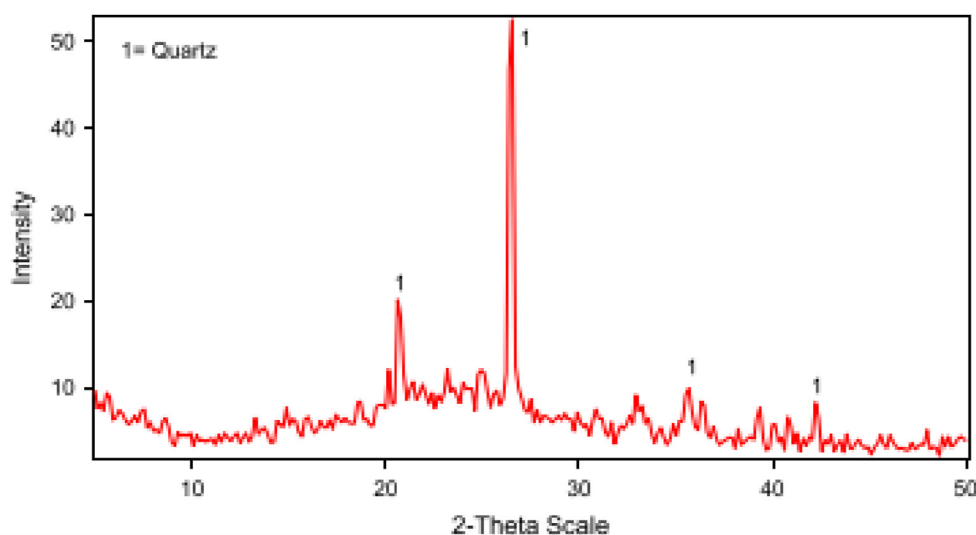


Fig. 1. X-ray diffraction (XRD) of metakaolin
Source: El-Diadamony et al. (2018).

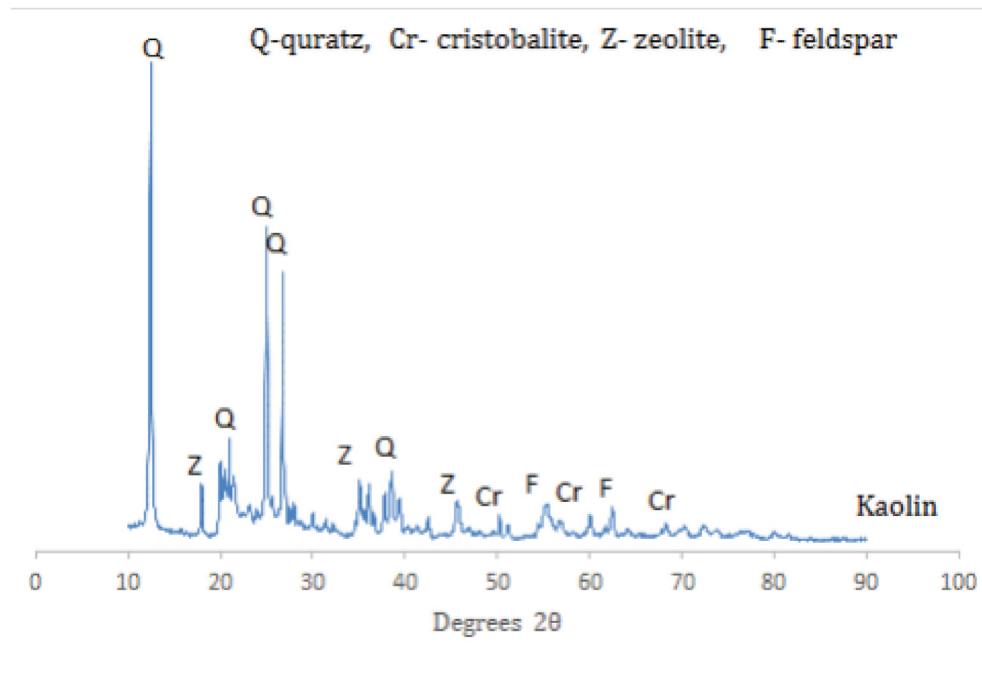


Fig. 2. X-ray diffraction (XRD) of metakaolin
Source: El-Diadamony et al. (2018).

1.3. Effects of metakaolin in mortar and concrete

Numerous researches have been done using pozzolans both natural and artificial as SCM in concrete production. Amongst some of the agricultural wastes used include: Corn Cob Ash (CCA), Rice Husk Ash, Neem seed Ash. In pursuit of ascertaining some technical benefits in the application of agricultural wastes in concreting, [Adesanya and Raheem \(2009\)](#) worked on blended cement using Corn Cob Ash as a replacement of OPC clinker at the level of factory production, it was discovered that less than 15% CCA was adequate in terms of mechanical properties of the mortar with corresponding low heat of hydration and consequently, higher setting time. The application of metakaolin and nanosilica as supplementary

material in concrete or mortar cannot be overemphasized. However, less attention has been given to inter-grinding metakaolin with OPC clinker from cement factory as thorough mixing of the cementing material is very important in the hydration process. In addition, the effect of kaolin source on the properties of concrete or mortar have not been adequately addressed.

[Sani et al. \(2017\)](#) carried out a research on the hydration reaction of metakaolin blended cement containing superplasticizer and opined 0.5 water/binder ratio as satisfactory. However, nanosilica was not incorporated, metakaolin from different sourced need to be looked into, properties without superplasticizer and at later curing ages should be considered. [Naresh \(2014\)](#) conducted a research using metakaolin infused with silica fume in the production of

Table 1
Chemical composition of metakaolin.

S/N0	Author	Chemical Composition (%)					
		SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	TiO ₂	K ₂ O
1	Stefanidou et al. (2017)	78.93	12.41	4.54	0.56	—	0.89
2	Alonge et al. (2017)	53.03	35.63	1.81	0.04	—	1.88
3	Madandoust and Mousavi (2012)	52.1	42.8	1.60	0.20	—	0.32
4	Ding and Li (2002)	51.2	45.3	0.60	0.05	—	0.16
5	AbdulRazak and Wong (2005)	57.4	35.3	0.94	—	0.43	3.17
6	Poon et al. (2006)	53.2	43.9	0.38	0.02	1.68	0.10
7	Guneyisi et al. (2012)	52.7	36.3	2.14	—	—	0.62
8	Tafraoui et al. (2016)	58.1	35.1	1.21	1.15	—	1.05
9	Ackay and Tasdemir (2018)	53.0	48.8	0.43	0.02	—	0.19
10	Chu and Kwan (2019)	55.3	43.6	0.44	—	0.70	—
11	Aroke et al. (2013)	53.8	40	1.29	0.15	2.44	0.45
12	Ayininuola and Adekitan (2016)	41.08	52.86	1.28	3.00	—	0.12
13	Akinyele et al. (2017)	51.25	40.70	1.18	0.32	—	0.20
14	Mitrovic and Nikolic (2012)	63.91	28.71	2.37	—	—	—
15	Rahul et al. (2018)	53	44	2.15	0.15	—	—
16	Navdeep et al. (2019)	52.10	41	4.32	0.39	—	—
17	Abdelli et al. (2017)	38.32	33.23	14.63	0.48	1.08	11.64
18	Zhenguo et al. (2018)	53.92	41.63	1.33	0.68	—	0.34
19	Al-Jabri and Shoukry (2018)	53.77	35.49	0.17	0.33	—	0.03
20	Ghasan et al. (2018)	52.22	41.41	0.49	0.08	0.01	1.73

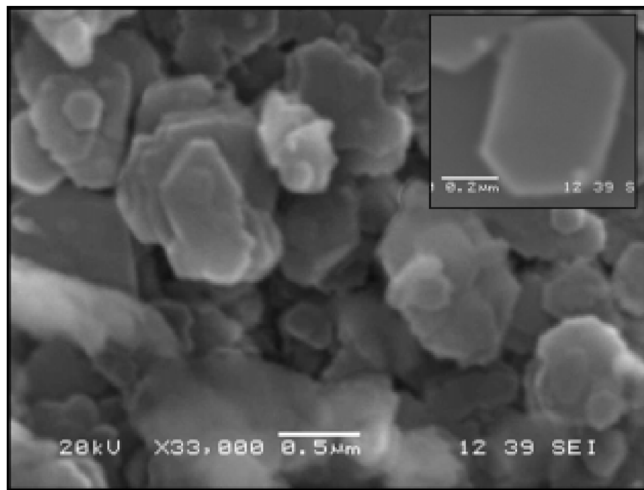


Fig. 3. SEM micrograph of metakaolin.
Source: Al-Jabri and Shoukry (2018).

concrete and observed improvement in the mechanical properties of concrete with 10% metakaolin in place of cement given satisfactory performance. Furthermore, Regina et al. (2019) carried out a research where incinerator residual ash was used joint with metakaolin as replacement of cement in concrete. It was found that 10% metakaolin replacement improved the hydration process of cement and consequently, the properties of the concrete. The work of Malagavelli et al. (2018) focused on the compressive, splitting tensile and flexural concrete infused with metakaolin. It was observed that 10% metakaolin replacement was higher than that obtained in the control sample. In addition, Mahyuddin and Alonge (2016) also concluded that 10% metakaolin as replacement of cement in Hybrid concrete enhanced the compressive strength during a research on early age mechanical strength of Hybrid Cementitious Composites. The work of Tawfiq et al. (2019) concluded that the flexural strength of concrete was satisfactory with 10% MK content.

Steve et al. (2017) worked on the mechanical properties of cement concrete composites containing nano-metakaolin. It was inferred that the improvement in compressive was optimum at 10% nano metakaolin replacement. Badogiannis et al. (2005) researched on the compressive strength of cement containing metakaolin and observed 10% metakaolin as cement replacement gave enhanced strength at 180 days of curing. The work of Qian and Li (2001); Courard et al. (2003) showed that the tensile strength and bending strength of concrete incorporating 10% metakaolin gave higher values compared to conventional plain mortar. Vu et al. (2001) examined the flexural strength of OPC blended with metakaolin and observed 10% metakaolin replacement performed satisfactorily when exposed to normal and adverse environment. Jin and Li (2003) concluded that the introduction of metakaolin enhanced the strength and modulus of elasticity development of at both early and late stage. Saleh et al. (2010) concentrated on the hardened and hydration properties of metakaolin blended cement cured in water for a period of 180 days and attention was not given to the properties of mortar in the fresh state.

The work of Siahmed et al. (2012) opined that the incorporation of MK in the range of 10–15% had satisfactorily enhanced the compressive strength of concrete at both early and later ages of curing with 10 and 15% MK replacement given value of compressive strength higher than the control at 28 and 60 days as shown in Fig. 4. In another research conducted by Brooks and Johari (2001), the compressive strength was found to increase as the percentage

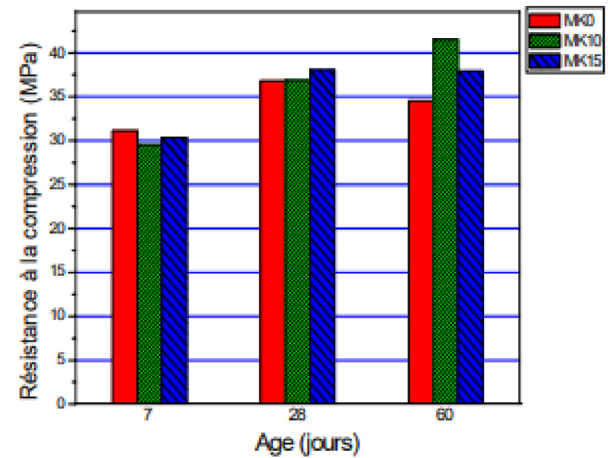


Fig. 4. Development of compressive strength of concrete containing metakaolin: Siahmed et al. (2012).

of incorporation increases with 10% MK exhibiting the peak value of compressive strength as shown in Table 2.

1.4. Nanosilica

It is a white powder otherwise called silicon dioxide nanoparticle has been one of the innovative materials in the concrete technology as a result of its high stability, strengthening and filling ability and minimal toxicity effects. Based on structural view, nanosilica is of two types: P-type and S-type nanosilica. The P-type nanosilica particles contain numerous nano-pores at pore rate of 0.61 ml/g, the S-type nanoparticles are known to have with small amount of nano-pores (AzoNano, 2013). Nanosilica could be synthesized adopting numerous methods amongst are: sol-gel process and biological means. In the sol-gel method, the parent material being Na_2SiO_4 and organometallics combined in solvent with immediate changes in PH and consequent attainment of a silica gel which is later cured and filtered (Sakka and Kosuko, 2000). However, the synthesis of nanoparticles could be grouped under the “top-down and bottom-up” approaches as presented in Fig. 5 (Rawat, 2014).

According to Jonckbloedt (1997); Dunster (2009) nanosilica synthesized by condensation of byproduct of silicon metals and ferro-silicon alloys in a cyclone through vaporization of silica in a temperature of between 1500 and 2000 °C in electric furnace thus producing powder with diameter of 150 nm and surface area of 15–25 m^2/g . Estevez et al. (2009) produced nanosilica of spherical shape through humus of red worms in containing about 22% of Silica dioxide adopting a biological method of production. In addition, nanosilica could be synthesized through method of precipitation in a temperature range of 50–100 °C using different precursors such as sodium silicates, burned rice husk ash, semi-burned rice straw ash, magnesium silicate (Thuadaj and Nuntiya, 2008). The choice of method of synthesis is greatly dependent on

Table 2

Compressive strength of concrete containing metakaolin.

Concrete mixes	Compressive strength (MPa)
OPC	87.0
MK5	91.5
MK10	104.0
MK15	103.5

Source: Brooks and Johari (2001).

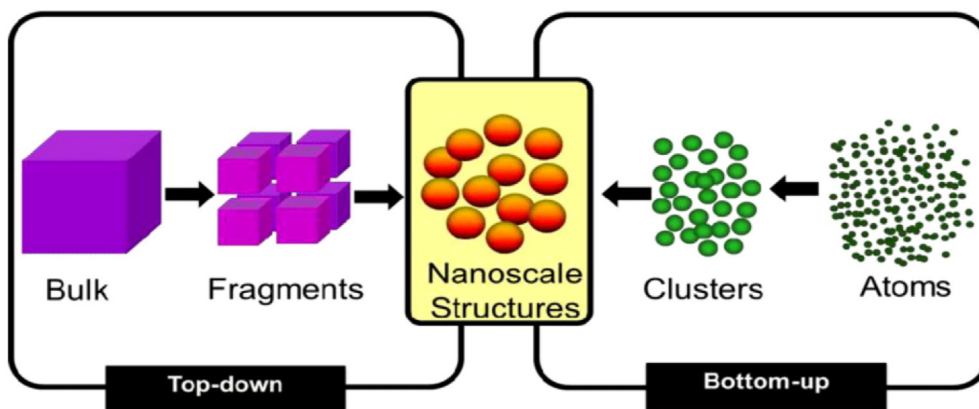


Fig. 5. Illustration of the “top-down” and “bottom-up” approaches in nanotechnology. Source: (Rawat, 2014).

the level of toxicity to human being with chemical method associated with some chemicals that could be of detrimental effects to human beings and biological method comprising of the use of extract from plants and microorganism for the process of synthesis and at the same time not having negative effects on the ecosystem (Saba, 2015).

1.5. Properties of nanosilica

The affirmation of synthesis of nanosilica is well ascertained when its properties are determined and compared with previous properties as established by other researchers and with standards. The characterization of nanosilica could be done through the following tests: UV–Vis spectroscopy, FTIR, SEM/EDX, XRF, XRD, Transmission Electron Microscopy, Thermo-gravimetric analysis (TGA) and many other depending on cost and the availability of equipment. The characterization depicts both the physical and chemical properties as well as the microstructural arrangement/pattern of the particles.

Yadav and Fulekar (2019) worked on the green synthesis and characterization of amorphous silica nanoparticles from fly ash and the micrograph of the SEM analysis shows that the shape of the nanosilica is spherical in nature and has the ability of forming clusters when stacked together see Fig. 6. In addition, the FTIR result as opined by Yadav and Fulekar (2019) showed silica bonding groups on three distinct regions as shown in Fig. 7 with corresponding wavenumbers of 475, 808, and 1105 cm^{-1} . The pattern of

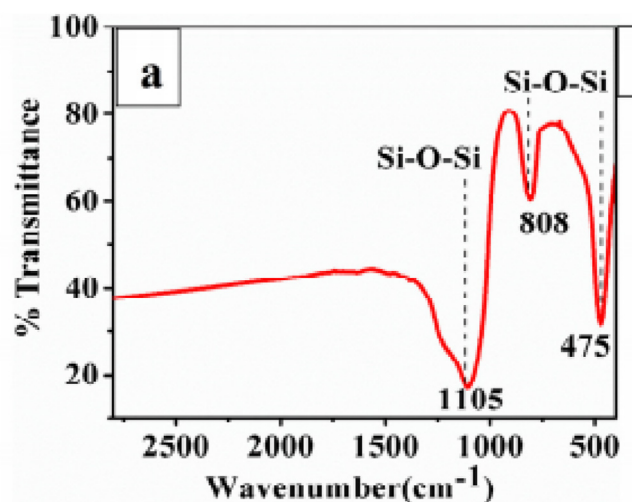


Fig. 7. FTIR spectra of nanosilica. Source: Yadav and Fulekar (2019).

the band being sharp at 475 cm^{-1} is due to flexural vibration of the Si–O–Si with the band at 808 cm^{-1} occurring as a result of vibration being symmetrical and that at 1105 cm^{-1} not symmetrical. The unavailability of bands in other region could be due to the pure nature of the silica. The XRD gives the mineral constituents present

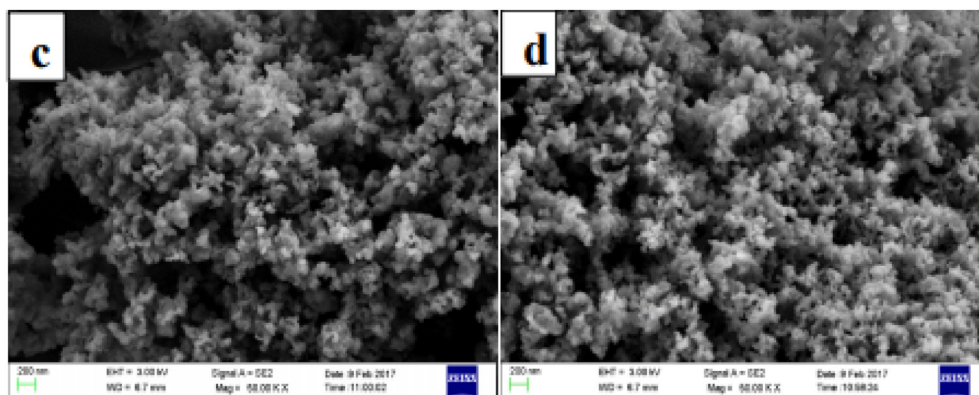


Fig. 6. SEM micrograph of nanosilica. Source: Yadav and Fulekar (2019).

in a particle as well as the arrangement/pattern of the mineral either crystalline or amorphous, properties which could be ascertained via the pattern of the intensity with the peak value. It could either be sharp or broad peak. The work of [Jinfeng et al. \(2017\)](#) characterized a nanosilica and the result of XRD as presented in [Fig. 8](#) showed that the highest intensity had broad peak of diffraction at (2θ) of 23° depicting the amorphous behavior of the particles. The peak intensity value is also in agreement with work of other researchers ([Abdelgawwad et al., 2017](#); [Yadav and Fulekar, 2019](#)).

1.6. Effects of nanosilica in concrete and mortar

Nanosilica enhances the cementitious properties of pozzolans when used in concrete or mortar. It has been concluded that the setting times of concrete declines with increase in nanosilica with corresponding increase in heat of hydration accompanied with high resistance of cement pastes and mortar to applied load under its service life ([Min-Hong et al., 2012](#); [El Aleem et al., 2014](#); [HouPeng-kun et al., 2013](#)).

[Hamdy et al. \(2018\)](#) conducted a study on the hydration characteristics and microstructure of cement pastes and mortars with and without nanosilica. The results showed that nanosilica increased the consistency and subsequently final setting time. In addition, it was observed that the addition of 1% nanosilica enhanced the mechanical properties of blended cement mortar as compared with the control. In another research conducted by [Hamdy et al. \(2017\)](#) on the chemical and engineering properties of blended cement using silica fume containing micro and nanosilica. The specimens were cured for 90 days' result gave maximum compressive strength with blending combination of (10% SF + 1% NS). However, biological synthesized form of nanosilica was not used, workability and setting times were not addressed and most importantly, the curing should be extended to about 365 days. [Satyajit \(2015\)](#) carried out experimental investigation to study the effect of nanosilica on the compressive strength of concrete at 0.3%, 0.6% and 1% Nano silica addition. From the compressive strength

results, an increase in strength was observed to be maximum for nanosilica addition at 1%. [Stefanidou \(2012\)](#) opined a strength increase of 25% on addition of between 0.5 and 2% nanosilica. The flexural strength at the ages of 3 days were observed to be maximum in the range of 1–2% nanosilica content. [Ali and Shadi \(2011\)](#) conducted work on the effects of silicon nanoparticles on physical and mechanical properties of high strength compacting concrete and concluded that the incorporation of 4% nanosilica at 28 days of curing gave a satisfactory compressive strength. [Shafiq et al. \(2019\)](#) worked on the effects of modified metakaolin using nanosilica on mechanical properties and durability of concrete. The results concluded that the combination of 10% MK & 1% NS performed satisfactorily well in terms of enhancement in the mechanical and durability properties of concrete with a w/b ratio of 0.35 in the presence of a superplasticizer and the curing of concrete was done for 90 days. Although, the metakaolin used was sourced from a location and blended was not a factory production blending, green form of nanosilica was not used and no attention was given to the characterization of the nanosilica. Furthermore, the work of [Pratyush and Sofi \(2018\)](#) opined that the addition of 10% MK and 1% nanosilica with a w/b ratio of 0.3 gave a very result in terms of compressive strength development at early age of curing. However, flexural strength, consistency, and setting times were not addressed. Also, the blending of the MK was done on site with cement and attention should be given to the properties of concrete at later ages; 365 days.

[Tawfiq et al. \(2019\)](#) opined an optimum combination of 20% MK and 4% NS with corresponding increase in compressive strength to about 16% at a w/b ratio of 0.35 in the presence of superplasticizer for a maximum of 90 days curing and attention was not given to the moisture absorption of the cement mortar. However, the MK used was obtained from one location and the mixing with cement was not a factory-based approach. Also, the materials were not characterized to determine its chemical composition, mineral constituents and microstructural imaging. The work of [Alonge et al. \(2017\)](#) concluded that the compressive strength cement mortar was found to increase with reduction in water absorption using a combination

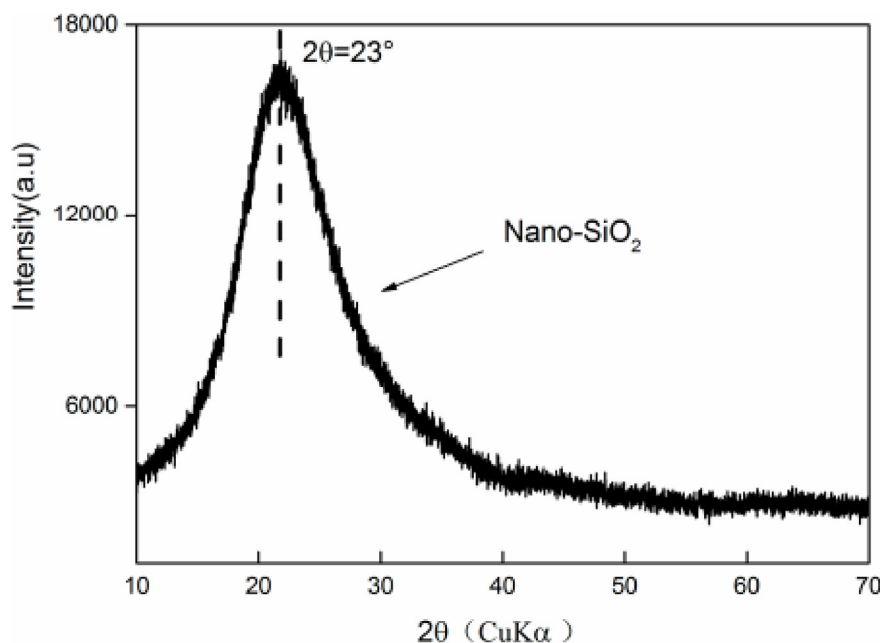


Fig. 8. X-ray diffraction (XRD) spectra of nanosilica
Source: [Jinfeng et al. \(2017\)](#).

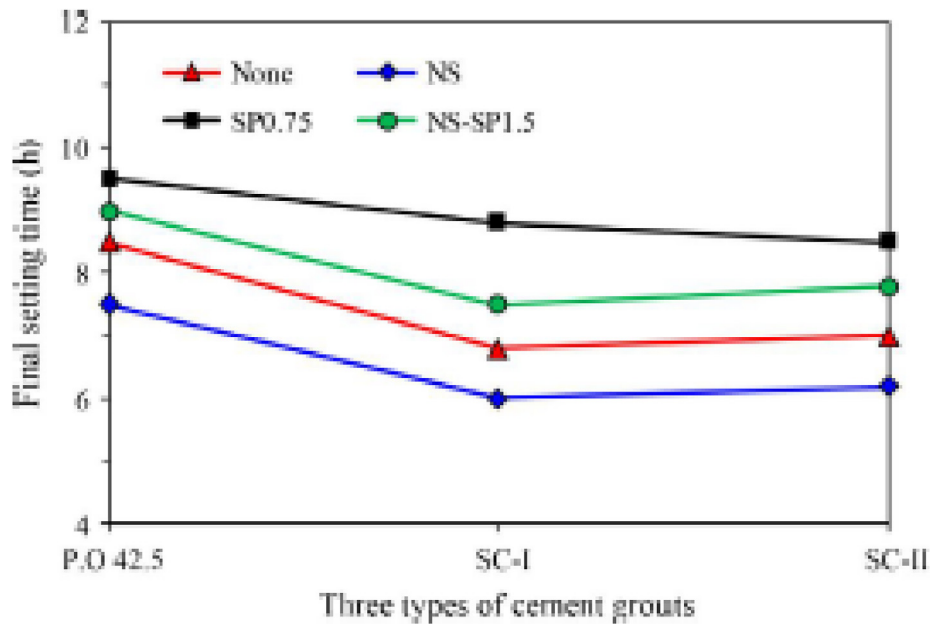


Fig. 9. Final setting time of different cement groutsSource: Li et al. (2019).

of 10% MK, 1% colloidal nanosilica and 1% epoxy in the presence of superplasticizer. However, the effect of location of the MK was not captured and the mixing of cement and MK was onsite and not factory blending approach. In addition, the microstructural properties of the resulting cement mortar were not considered. Nazari and Riahi (2011) observed that the addition of nanosilica was found to improve the pore refinement of self-compacting concrete and consequently, decrease in the rate of water absorption as the content of nanosilica increased. Furthermore, this reduction could be attributed to inadequate dispersion of high quantity of nanosilica content. However, the nanosilica was sourced via chemical approach form of synthesis and polycarboxylate admixture was added to the composite. The addition of nanosilica had greatly

influenced the properties of cement mortar and it has been reported that nanosilica infused to ordinary Portland cement paste enhanced strength development at early ages along with increase in pozzolanic activity Qing et al. (2007); Stefanidou (2012). Rao and Maruthi (2016) carried out experimental investigation on the use of metakaolin and nano silica on concrete properties. It was observed that concrete prepared with a combination of 5% metakaolin and 2% nanosilica indicated increased strength compared to the controlled concrete.

Khomich et al. (2016) performed a research on the use of nanosilica as a modifier in cement mortar and could make that inference that 1% nanosilica addition reduced the water absorption and at the same time improved the strength of the cement mortar.

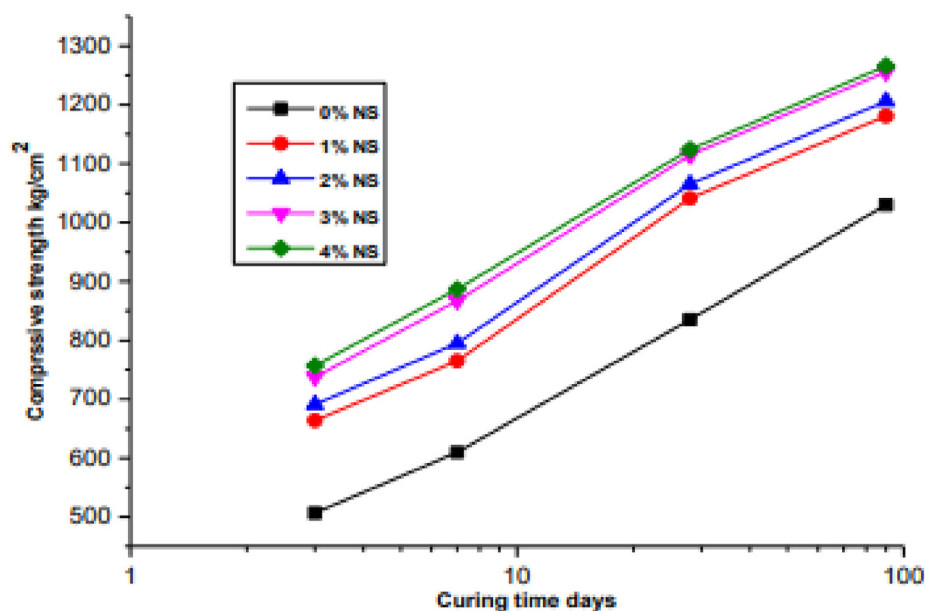


Fig. 10. Compressive strength of blended basalt cement paste containing nanosilica with curing time. Source: Khalil (2016).

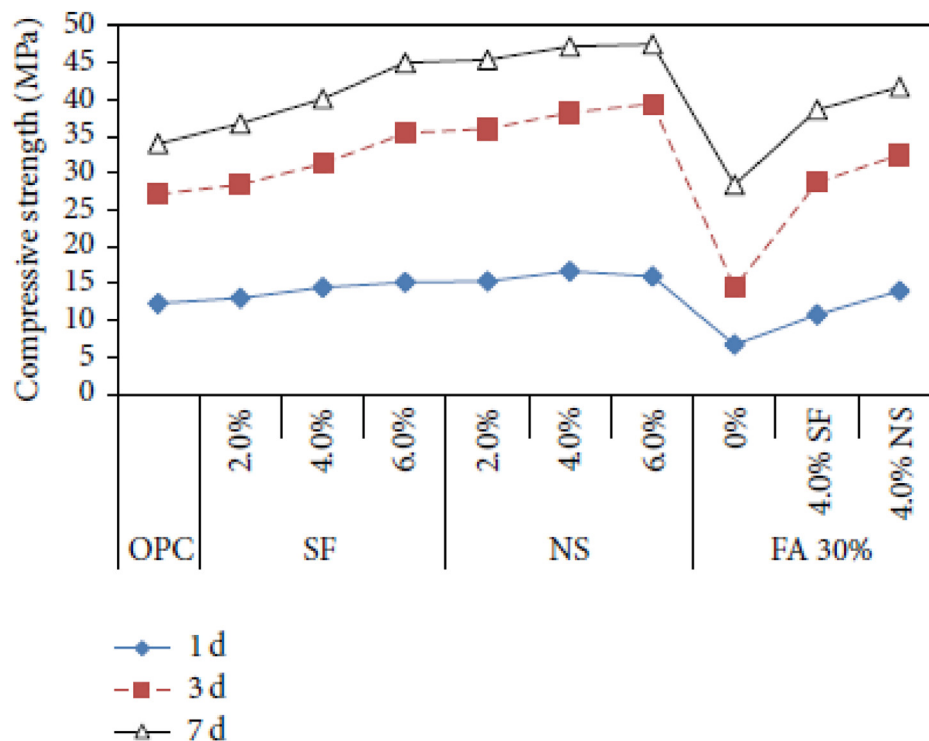


Fig. 11. Early age compressive strength of composite cement Pastes
Source: [Chen et al. \(2016\)](#).

However, the workability of mortar in the fresh state was not addressed. The work of [Adnan et al. \(2018\)](#) focused on the effects of nanosilica on early strength of cement mortar using 0.45 w/b ratio

where 2% nanosilica was found to improve mechanical properties of fly ash mortar with a decline in strength when at 4% nanosilica. Also, the consistency of the paste was not satisfactory with the 0.45

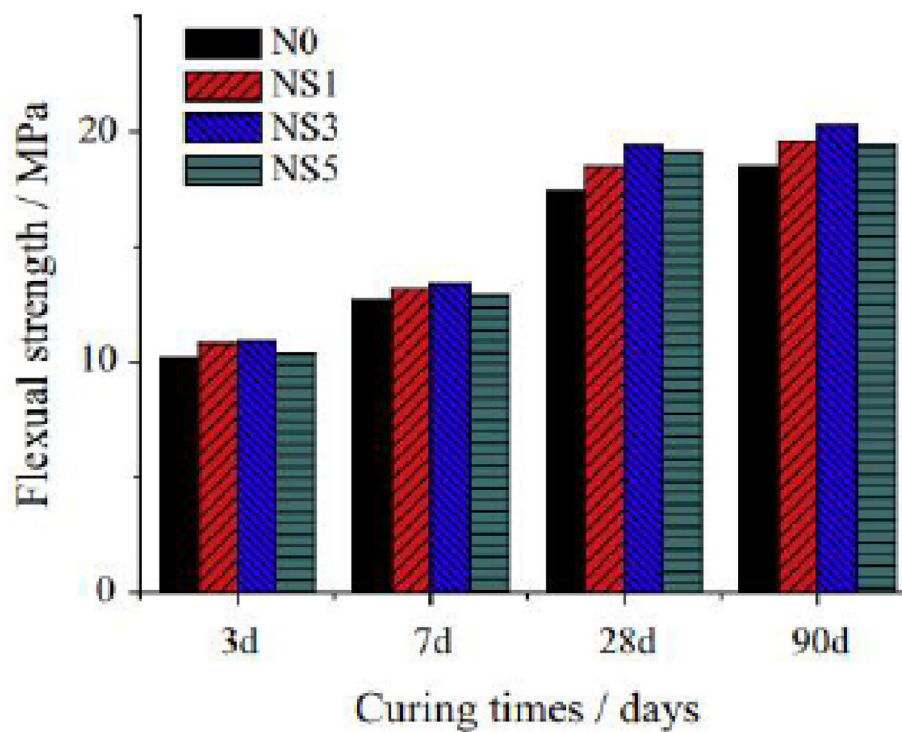


Fig. 12. Flexural strength of concrete modified with Nanosilica
Source: [Rong et al. \(2015\)](#).

w/b ratio adopted. However, the metakaolin was not interground at the level of factory production, green form of synthesized nanosilica was not adopted with percentage addition not to a level of 5%. Shaikh et al. (2014) concluded that 2% nanosilica improved strength of mortar in a range of 33–48% when an experiment on the study on the effects of nanosilica on compressive strength of high-volume fly ash mortars and Concrete was carried out. However, workability and setting times were not addressed and the need to cure for later ages is very essential. Jinfeng et al. (2017) opined 3% enhancement in pore refinement with the addition of 3% nanosilica during the investigation of the effects of nanosilica on the early hydration of alite sulphoaluminate cement. Although, the work did not address the consistency of the mortar in the fresh state as more attention was given to microstructural development. The application of nanosilica in mortar has the capability of reducing its setting time as against that of a silica fume and as well as minimizes separation of concrete constituents in the fresh state with reduction in the tendency of bleeding and at the same time enhancing better mixture cohesiveness (Collepari et al., 2002; Li et al., 2006). Also, Fig. 9 revealed where the addition of nanosilica was found to reduce the setting time of different cement grouts as opined in the work of Li et al. (2019). The work of Khalil (2016) focused on the effects of nanosilica on the properties of blended basalt cement paste. The results concluded an enhancement in strength development at both early and later ages of 90 days with the incorporation of nanosilica up to 4% given better results compared to the control experiment as presented in Fig. 10. However, the blending of the basalt and cement was not done at the level of factory production. Also, the consistency and setting times of the paste were not considered. Fig. 11 showed the work of Chen et al. (2016) where early strength of cement composites blended with silica fume (SF) and fly ash (FA) when incorporated with nanosilica. The result showed that nanosilica enhanced the strength of composite at early stage as compared to the control and other composites. However, the work did not consider the synthesis of the nanosilica, later strength development was not captured and water absorption was not determined. According to the work of Rong et al. (2015) the incorporation of nanosilica at all levels of addition were observed to enhance the flexural strength of concrete at different curing ages with optimum strength attained at 3% nanosilica (see Fig. 12). This is in contrary to the work of Li et al. (2015) where 1% of nanosilica was observed to give the optimum flexural strength ultra-high-performance concrete.

2. Conclusion

In conclusion, the applications of nanosilica in concrete technology cannot be overemphasized as it greatly has influence on the properties of concrete and mortar both in fresh and hardened states. Also, nanosilica has been shown to fill the micro pores in concrete thereby improving its microstructural arrangement and thus producing a well dense concrete. Furthermore, metakaolin has been found to be unique amongst other pozzolans in terms of its satisfactory performance and most especially being a natural pozzolans existing in form of clay. Although, from previous researches little attention had been given to the influence of the source of the metakaolin on its pozzolanic tendencies and consequently, limited works on the application of metakaolin as an additive at the level of production of factory blended cement; as in most cases have been used admixture by mixing directly with cement on site.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have

appeared to influence the work reported in this paper.

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