A Study of the Mechanical Properties of Waste Nano Ceramic Concrete Incorporating Nano-Sio_2 Particles

Taher A. Tawfik
Department of Construction and Building
Higher Institute of Engineering,
Giza, Egypt

S. A. EL-Beshlawy
Department of Construction and Building
Higher Institute of Engineering,
Giza, Egypt

Khaled Aly Metwally
Department of Construction and building
Higher Institute of Engineering,
Giza, Egypt

A. Serag Faried
Department of Civil Engineering
Faculty of Engineering, Fayoum University,
Fayoum, Egypt

Abstract:- **Waste material recycling through using in concrete manufacturing not only provides a promising resource to produce a high quality concrete, but also helps to properly encounter the problem of waste disposal. It is a good option for use in concrete because waste ground ceramic has a highly resistant structure and cannot be processed by any recycling system and because it is produced in large quantities. Thus, this study focused on three different phases: in the first phase, the use of waste ceramic power which milled to waste nano ceramic (WNC) as a pozzolan in concrete was investigated. Concrete samples with 2, 4, 6, 8 and 10% of waste nano ceramic (WNC) substitution were made. In the second phase of the study, 1–4% of nano-SiO_2 was used as a partial replacement from cement which chemical prepared. The simultaneous effect of using the optimum percentage 3% of nano-SiO_2 incorporating with 6% of waste nano ceramic (WNC) was determined (phase c). In all cases, mechanical tests (compressive, slitting tensile and flexural strength) were performed. The results show that replacing waste nano ceramic (WNC) up to 6% and nano-SiO_2 up to 3% does not have a significantly negative effect on the mechanical properties of concrete. Furthermore, using any amount of nano ceramic (WNC) in the concrete increase its mechanical properties. In addition, using nano-SiO_2 and pozzolan simultaneously leads to improved compressive strength and a reduced water absorption capacity. Therefore, nano-SiO_2 can improve the effects of ground ceramic powder on the properties of concrete.**

Keywords: Waste nano ceramic , milling, Nano-SiO_2 , mechanical properties, waste nano ceramic concrete incorporating nano-SiO_2

I. INTRODUCTION

Reducing the necessary amount of Portland cement without reducing the performance of concrete is significant for big projects that require a large amount of cement. Furthermore, Portland cement clinker production consumes large amounts of energy and has a notable environmental impact, which involves massive quarrying for raw materials because it 1.7 tons are required to produce 1 ton of clinker and the emission of greenhouse and other gases into the atmosphere. Approximately 850 kg of CO_2 is emitted per ton of clinker produced [1,2]. Hence, pozzolan and cementitious materials play an important role in concrete production. In recent years, the disposal of waste materials has presented a complex problem for many agencies worldwide, and industries must find ways to reuse their wastes [3]. The replacement of cement in concrete by wastes represents a tremendous saving of energy and has important environmental benefits. In addition, it will also have a major effect on decreasing concrete costs because the cost of cement represents more than 45% of the cost of concrete. According to some authors, the best way for the construction industry to become more sustainable is by using wastes from other industries as building materials [4]. Ceramic wastes, which are durable, hard and highly resistant to biological, chemical and physical degradation forces, cannot be recycled by any existing process. The use of inorganic industrial residual products in the production of concrete will lead to sustainable concrete design and a greener environment [5]. The amount of waste in the different production stages of the ceramic industry ranges from 3% to 7% of daily production [1]. A number of previous studies have examined the use of waste ceramic in concrete as an aggregate replacement [5–8] or partial cement replacement [8–13], such as pozzolan. Lavat et al. [10] observed a decline in strength at early ages. Ay and -nal confirmed the pozzolanic reactivity of waste ceramic powder [9], and Toledo Filho et al. [11] measured a slight increase in compressive strength for cement replacement by brick powder of up to 10–20%. Torgal and Jalali [8] reported a slight decrease in compressive strength and a decline in water permeability and chloride ion diffusion in concrete with 20% of ground ceramics used as Portland cement replacement.

On the other hand, Nanotechnology is one of the most important sciences where many researchers studied its effect. Nanotechnology plays an important role in clean up the environment.[14–19] Ferdinand Brandl and Nicolas Bertrand demonstrated a method for using nanoparticles and ultraviolet (UV) light to quickly isolate and extract a variety of contaminants from soil and water.[16] In recent years,

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 8 Issue 03, March-2019

nanoscale zero valent iron (nZVI), carbon nanotubes and nanofibers were applied for the remediation of a variety of contaminants including chlorinated compounds, hydrocarbons, organic compounds and heavy metals.[18] Nanowaste materials consumed in concrete production is a valuable issue in clean-up the environment. Priya and Vinutha [20] and Givi et al. [21] studied the effect of nanosilica on the rice husk ash concrete. Rice husk ash concrete provides a clean environment by reducing the burning of rice husk ash problem, which is an environmental catastrophe. Presence of nanomaterials in concrete affects its properties. Because of the abundant usage of concrete in the construction, its quality should be improved. Concrete is a highly heterogeneous material produced by mixing of finely powdered cement, aggregates of various sizes with water through inherent physical, chemical and mechanical properties.[14] Colston et al. [22] investigated the effect of inorganic nanoparticles and zeolites on concrete microstructure. The researchers verified the improvement of concrete microstructure using microelectronics scanning and X-ray fluorescence analysis. Most of the studies investigated the effect of using nanoparticles in cement and concrete utilizing SiO_2 and Fe_2O_3 [23,24]. Jaishankar and Saravana Raja Mohan [25] studied the mechanical properties of nano-SiO_2 and nano-Al_2O_3 concretes. Four different types of ratios were used (0.5, 1, 1.5 and 2). Jaishankar proved that compressive and flexural strength measured at 28th day of the concrete mixed with nano- SiO_2 and nano-Al_2O_3 were higher than that obtained from a plain concrete mix. The incorporation of nanoparticles significantly resisted the cracking behavior of concrete. The influence of nano-ZrO2 (NZ), nano-Fe3O4 (NF), nano-TiO2 (NT) and nano- Al_2O_3 (NA) on mechanical properties including the compressive and indirect tensile strength in addition to durability of concrete were investigated by Shekaria and Razzaghi.[26]. El-Yamani et al [27] also studied the effect of replacement of cement with different percentages of (1, 2, 3 and 4%) Nano-SiO_2 and with constant percentage of silica fume, which the result showed that nano-Sio_2 is used to reduce the corrosion in reinforcement bars. Sololev and Guti_errez [28] mentioned that, the NS acting as a nanofiller in the voids or empty spaces or between particles of calcium silicate hydrate (C–S–H) gel. NS is scatted in the hydration process acting as a nucleation or crystallization centers, by this way the hydration rate increased. As well, NS assisted in the formation of smaller size CH crystals and homogeneous clusters of C–S–H composition. Moreover, researchers founded that NS improves the structure of the transition zone between aggregates and paste. The present work aimed to investigate the effect of using NS and waste nano ceramic (WNC) on the concrete. The mechanical properties including, compressive, flexural and splitting tensile strength are discussed in this article. A comparison was carried out between the improvement ratios obtained by using NS prepared chemically and that obtained from nanowaste materials (WNC), which prepared by mechanical milling and that was the main objective of the present work.

II. MATERIALS

A. Waste ceramic

The waste ceramic used in this study was obtained from recycled ceramic ground tile supplied by cleopatra ceramic factory in Egypt. Cracked pieces of ground tiles were crushed by tabin crusher. At the laboratory scale, Nanowaste materials used are NFA, NSF and NC. Torefine the particles of fly ash, SF and coal from micro- to nanosize high energy milling technique was used. There are different types of milling machines for example milling machine having a rotating cylindrical container along its axis horizontally, planetary milling machine, SPEX shaker mills.[29] Borner and Eckert [30] investigated the effect of energy input by milling iron powders with the use of a SPEX milling machine and a Pulverisette 5, among other lower energy mills. SPEX shaker mill provides the largest input and, therefore, leads to a fast decrease in grain size to lessthan 20 nm. The Pulverisette mill provides a smaller energy impact during the. collision. After 32 hours of milling, the grain size achieved was 40 nm at 90 rpm,

31nm at 180 rpm and 20nm at 360 rpm. The machine used for milling in this research was Fritsch Pulverisette Analyzer, which milling was fixed to 400 rpm. The milling process performed with 2.5mm diameter ball and jar type were fixed to zirconica oxide, Fadzil et al. [31] prepared the nanometakaolin with the same method but using different diameter for the ball. The waste ceramic preparation process before milling is shown in Fig. 1.

Fig.1. ceramic preparation process: (a) raw ceramic ground and grinded by hammer mill, (b) grinded by tabin crusher, and powdered by tabin mill.

B. Nanosilica.

The nanosilica used in this research was prepared at the Beni Suef central laboratories. The particle sizes (nm) and specific surface area (m^2/kg) of nano-SiO_2were 14 and 200, respectively. Table I illustrates the chemical composition of nano-SiO_2.

Table I chemical properties of nano-SiO_2

content	Content (%)
SiO_2	99.65
TiO_2	0.02
Al_2O_3	0.01
Fe_2O_3	0.012
MnO	<0.01
MgO	<0.01
CaO	<0.01
Na_2O	<0.01
K_2O	<0.01
P_2O_5	<0.01
LOI	0.25

Cement

OPC was used in all mixes, which produced by Misr Beni Suef company (Beni Suef city, Egypt). CEM I 52.5 N was a cement grade used. Cement was tested according to ASTM C150. The physical and mechanical properties and chemical composition of the cement are shown in Table I.

.Table II the Portland cement of physical and mechanical properties

No.	Property	Result
1	Specific gravity	3.15
2	Fineness	3200 cm^2/g
3	Initial setting time	86 minutes
4	Final setting time	195 minutes
5	Compressive strength	Kg/cm^2
a)	3 days	205
b)	7 days	307
c)	28 days	436
6	Soundness	1mm
6	chemical composition %	Wt,(%)
a)	SiO_2	21.16
b)	Al_2O_3	5.50
c)	Fe_2O_3	3.21
d)	MgO	0.69
e)	CaO	63.40
f)	SO_3	2.40
g)	K_2O	0.50
h)	Na_2O	0.10
i)	F.L	2.70
j)	LOI	2.30

D. Aggregates

The sand and the coarse aggregate used in the concrete were Crushed dolomite aggregates. The water absorption, specific gracity, density and void ratio(%) of the aggregates were specified following the tests methods described in ASTM. The physical properties of the aggregates are given in Table III.

Table III physical properties of dolomite and sand

No.	Property	Result	
		dolomite	sand
1	Specific gravity	2.66	2.65
2	Bulk density kg/m^3	1600	1850
3	Void ratio(%)	39.84	37.73
4	Percentage of absorption (%)	1.80	2

E. Water

The water used in the concrete was Tap water.

F. Superplasticizer

In this study, the chemical admixture used as superplasticizer was high range water reducer of modified polycarboxylates. It was manufactured according to ASTM C494 (types F). The chemical admixture main concept controls the total performance, whereas allows cement particles delayed absorption and distributed them. High range water reducer superplasticizers obtained a high-quality concrete mix with high strength. Table 6 shows Properties of the superplasticizer.

Table IV Technical Data Properties of the superplasticizer

Form	Aqueous solution of modified polycarboxylates
Appearance	Brown liquid
Density	1.185 kg/liter
pH value	4.5-4.9

III. MIX PROPORTIONS

The present investigation studied the partial replacement of cement by waste nano ceramic powder (phase A) as well in phase B studied the partial replacement of cement by waste nano-SiO_2. Also, the reduced the cement content by adding several combinations of a ceramic powder and nano-SiO_2 (phase B). The mixture is designed according to ACI-211-89. At the beginning of the mixture design, the binder content (350 kg/m3) and water–cement ratio (0.45) were chosen to be constant.

A. Phase A

Mixes were made with waste nano ceramic replacing 0%, 2%, 4%, 6%, 8% and 10% by weight of the cement as pozzolan and with the same amount of reference. The amounts in the concrete mixture are shown in Table V.

B. Phase B

The objective was to produce high strength pozzolanic concretes nano-SiO_2. Mixes contained 1-4% nano-SiO_2 and different proportions of WNC as shown in Table V. Third high strength concrete mixes were optimized and used in the current study.

C. phase C

Accordingly, concrete mixtures using different mix proportions and optimum percentages combinations of WNC and nano-SiO_2 were initially performed. Eight high strength concrete mixes were optimized and used in the current study. Mixes used the optimum percentage 3% of nano-SiO_2 incorporating with 6% of WNC.

Table V Mix composition of the investigated samples

MIX NO.	O.P.C %	N.S %	N.C %
C0	100	0	0
C1	99	1	0
C2	98	2	0
C3	97	3	0
C4	96	4	0
CC2	98	0	2
CC4	94	0	4
CC6	96	0	6
CC8	92	0	8
CC10	90	0	10
C3+CC6	91	3	6

C0: control
C1-4:1-4%nano silica
CC2,4,6,8,10: waste nano ceramic

IV. MIX DESIGN

The concrete mixtures were mixed in accordance with ASTM C 192 in a 120 l drum mixer. The coarse and fine aggregate were mixed first, followed by the addition of the cement, pozzolan and water containing the required amount of Superplasticizer. One fifth of the Superplasticizer was always retained to be added during the last 1 min of the mixing period. The Superplasticizer admixture was used in various amounts to maintain the workability of the fresh concrete. Nanoparticles are not easy to distribute uniformly due to their high surface energy. In order to solve this problem in the previous studies, before adding any nanosilica to the mixture, nanosilica was stirred separately for 1 to 3 min at high speed using with either water or water and Superplasticizer. Having made sure that the particles have been completely dissolved in water, they were added to the mixture. [32]. Therefore, in phase B, particles were stirred in water for 1 min at 120 rpm, and then they were added to the mixture. The test specimens were cast in steel cubic moulds (100 X 100 X 100) and compacted on a vibrating table. After approximately 24 h, the specimens were removed from the moulds. The concrete specimens were cured in lime-saturated water at 21 ◦C in cure tanks until the time of testing. Casting, compaction, and curing were accomplished according to ASTM C 192-81. For each mix, cubic samples were tested to determine the compressive strengths at 7 and 28days of curing. The compressive strength for each mixture was obtained from an average of three cubic specimens. A 2000-kN capacity uniaxial compressive testing machine was used to test the specimens.

V. RESULTS AND DISCUSSION

A. Compressive strength in phase A

The average results obtained from the sample compression tests at 7and 28, days are shown in Fig. 2 and given in Table VI. The results obtained indicate, as expected, differences at early curing ages. The7th day compressive strength varied between 252 and 284 kg/cm^2, and the 28th day strength varied between 286 and 310 kg/cm^2. he highest improvement was observed at 6% WNC. The compressive strength decreased as the proportion of waste ground ceramic in the concrete produced increased. At early curing ages, pozzolan only acts as filler and does not undergo the pozzolanic reaction. The reduction in the early compressive strength is mainly due to the immature pozzolanic reaction in the concrete and the preventive growth of C–S–H gel affected by components in nano waste ceramic [33-34].

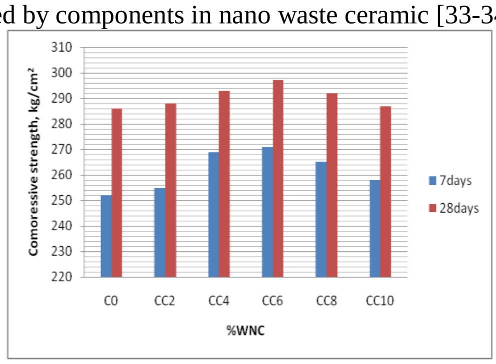


Fig.1. Compressive strength of concrete containing different percentage of waste nano ceramic at 7 and 28 days of hydration.

B. Compressive strength in phase B

Different NSF percentage specimens are compared to control specimens. The effect of curing age on the compressive strength of the concrete mixes at 7and 28 days is presented in Figure 3. The optimum result of compressive strength was at 28 days and with 3% NS by weight of the cement content (C3). Low compressive strength improvement is observed at higher and lower than 3%. The increase in the compressive strength can be attributed to the reaction between the calcium hydroxide present already in lime solution and the nanoparticles resulting in formation of additional C–S–H gel, which is responsible on the compressive strength increase [35]. Tawfik et al. [36] and Ghafari et al [37] confirmed that the optimum amount of cement replacement by nano-SiO_2 in cement paste to achieve the highest compressive strength was 3wt%, which agreed with the present work.

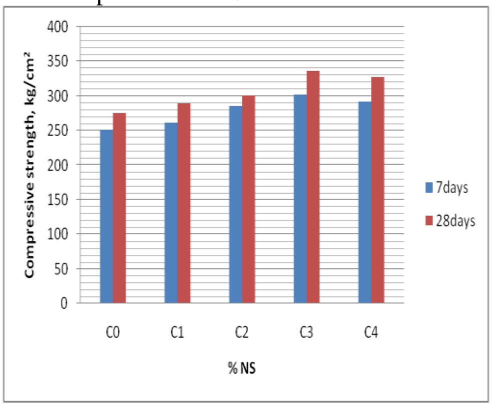


Fig.3. Compressive strength of concrete containing different percentage of nano-SiO_2 at 7 and 28 days of hydration.

C. *Compressive strength in phase C*

The results of compressive strength for all of the concrete mixture used in phase C are presented in Fig. 4. and is shown in Table **VI**. In general, the compressive strength of the concrete specimens decreased as increasing amounts of waste nano ceramic was replacment. As more cement was replaced by waste nano ceramic, lower compressive strengths were observed. Furthermore, the addition of nano-SiO_2 is helpful for the improvement of the compressive strength in the concrete specimens. The compressive strength developed in concretes containing nano-SiO_2 particles was higher than that of the control sample in every case higher. As mentioned above, nano-SiO_2 is thought to be more effective in the pozzolanic reaction than waste nano ceramic. The strength of the concretes was found to increase as the nano-SiO_2 content increased from 1% to 3%. However, it should be noted that using a higher content of nano-SiO_2 must be accompanied by adjustments to the water or superplasticizer dosage in the mix to ensure that specimens do not suffer excessive self desiccation and cracking. Otherwise, using this much nano-SiO_2 could actually lower the strength of composites instead of improving it, although this was not observed in this study.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 8 Issue 03, March-2019

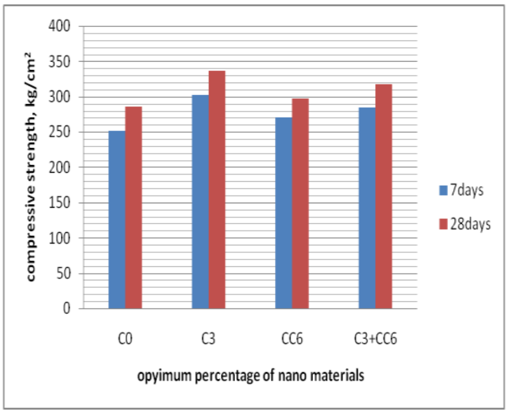


Fig.4. Compressive strength of concrete containing optimum different percentage of waste nano ceramic and nano silica at 7 and 28 days of hydration.

TableVI Results of compressive and splitting tensile and flexural strength tests

Mix No	Compressive strength Kg/cm²		Splitting tensile strength Kg/cm²	Flexural strength kg/cm²
	7days	28days	28days	28 days
C0	252	276	22	34
C1	262	290	24	35
C2	286	301	25	36
C3	302	337	26	37
C4	292	328	24	36
CC2	255	288	23	34
CC4	269	293	24	35
CC6	271	297	25	36
CC8	265	292	24	35
CC10	258	287	23	34
incorporating (3%NS+ 6% NC)	284	317	25	36

D.SEM Test

To verify the mechanism predicted by the compressive strength test, scanning electron microscope (SEM) examinations are performed. Some samples from all experimental specimens are exposed for the electrographic at a specific period (28 days). This can be shown from Figures (5-b) Nano-SiO_2 samples have more consolidated and occupy structure compared with the control sample.

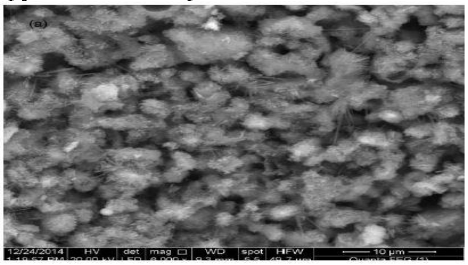


Fig 5. (a) SEM of control sample of concrete

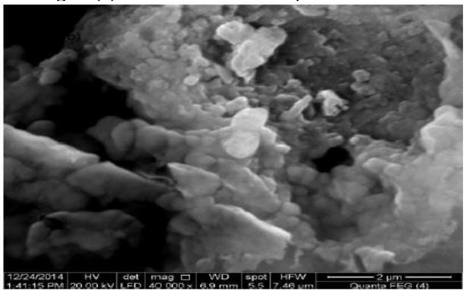
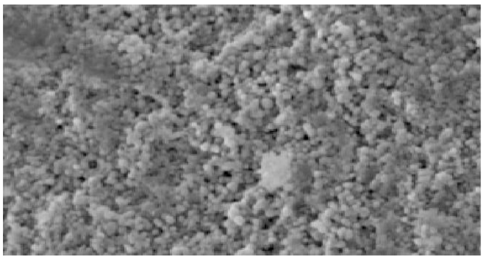


Fig 5 (b) SEM of sample containing 3% Nano-SiO_2



(c) SEM of sample containing 6% waste nano ceramic

VI. CONCLUSIONS

The possibility of using waste ground ceramic powder and the combination of ground ceramic powder with nano-SiO_2 as a replacement for cement has been investigated in this study. The waste nano ceramic was used in quantities of up to 10% and nano-SiO_2 was 1- 4% of the cement. The following conclusions can be drawn from the study:

1. The compressive strengths of samples decrease with increasing WNC content, especially at early stages. However, the results show that concrete with WNC ultimately demonstrates only minor strength loss, and WNC exhibits very good pozzolanic reactivity and can be used as a cement replacement. For less than 8% use of the pozzolan, the average decrease in resistance after 7 and 28 days of curing is 2.64% and 1.74%, respectively. This results show that less than 8% replacement of pozzolan has no considerable effect on resistance.
2. Nano-SiO_2 improves the mechanical properties of pozzolanic samples. The greatest impact of adding nano-

SiO_2 on compressive strength was observed at early curing ages. Because the reduction of the compressive strength of concrete due to the use of pozzolanwas determined at an early stage, the addition of nano-SiO_2 could effectively compensate for it. In addition, using nano-SiO_2 resulted in increased slitting and flexural strength in all samples. The use of both WNC and nano- SiO_2 resulted in a dramatic increase in the mechanical of concrete.

3. A very slight difference in the mechanical properties of concrete with the use of 3% or 4% of nano-SiO_2 was observed. Increasing the amount of pozzolan improved the mechanical properties of concrete more in samples with 3% nano-SiO_2 compare to those with 4% nano-SiO_2, so it can be concluded that the optimum percentage of nano-SiO_2 is between 3%.

4. Using this construction industry waste product in the production of concrete converts it into an environmentally friendly material because it reduces the agglomeration of residues and exploits its incorporated energy.

REFERENCES

[1] Meyer C. The greening of the concrete industry. Cem Concr Compos 2009;31:601–5.
[2] Gartner E. Industrially interesting approaches to low-CO2 cements. Cem ConcrRes 2004;34(9):1489–98.
[3] Fernandes M, Sousa A, Dias A. Environmental impact and emissions trade ceramic industry. A case study. Portuguese Association of Ceramic Industry APICER; 2004.
[4] Mehta PK. Reducing the environment impact of concrete: concrete can be durable and environmentally friendly. Concr Int 2001;10:61–6.
[5] Khaloo AR. Crushed tile coarse aggregate concrete. Cem Concr Aggr 1995;17(2):119–25.
[6] Lopez V, Llamas B, Juan A, Moran J, Guerra I. Ecoefficient concretes: impact of the use of white ceramic powder on the mechanical properties of concrete. Biosyst Eng 2007;96(4):559–64.
[7] Guerra I, Vivar I, Llamas B, Juan A, Moran J. Ecoefficient concretes: the effects of using recycled ceramic material from sanitary installations on the mechanical properties of concrete. Waste Manage (Oxford) 2009;29:643–6.
[8] Torgal F, Jalali S. Reusing ceramic wastes in concrete. Constr Build Mater 2010;24:832–8.
[9] Ay N, -nal M. The use of waste ground ceramic in cement production. Cem Concr Res 2000;30(3):497–9.
[10] Lavat A, Trezza M, Poggi M. Characterization of ceramic roof tile wastes as pozzolanic admixture. Waste Manage (Oxford) 2009;29:1666–74.
[11] Toledo Filho RD, Gonçalves JP, Americano BB, Fairbairn EMR. Potential for use of crushed waste calcined-clay brick as a supplementary cementitious material in Brazil. Cem Concr Res 2007;37:1357–65.
[12] Naceri A, Hamina M. Use of waste brick as a partial replacement of cement in mortar. Waste Manage (Oxford) 2009;29:2378–84.
[13] Puertas F, Garcia-Diaz I, Barba A, Gazulla M, Palacios M, Gomez M, et al.Ceramic wastes as alternative raw materials for Portland cement clinker production. Cem Concr Compos 2008;30:798–805.
[14] M. Mahmoudi, M. H. Behbodi, S. H. Sedigh ziabari. Role of nano technology in the construction industry to reduce environmental pollution. J. Environ. Sci. Technol., 2008, 10, 3.
[15] F. Pacheco-Torgal, S. Jalali. Nanotechnology: advantages and drawbacks in the field of construction and building materials. Construct. Build. Mater., 2011, 25, 582–590.
[16] F. Brandl, N. Bertrand, E. M. Lima, R. Langer. Nanoparticles with photoinduced precipitation for the extraction of pollutants from water and soil. Nat. Commun., 2015, 6, 7765.
[17] A. Singh. Nanoparticles for environmental clean-up: an overview. Int. J. Appl. Chem., 2016, 12, 175–181.
[18] S. S. Patil, U. U. Shedbalkar, A. Truskewycz, B. A. Chopade, A. S. Ball. Nanoparticles for environmental clean-up: a review of potential risks and emerging solutions. Environ. Technol. Innov., 2016, 5, 10–21.
[19] N. Wilson. Nanoparticles: environmental problems or problem solvers? Bioscience., 2018, 68, 241–246.
[20] K. V. Priya1, D. Vinutha. “Effect of nano silica in rice husk ash concrete”: International Conference on Advances in Engineering & Technology (ICAET-2014). J. Mech. Civil Eng., 2014, 39–43.
[21] A. N. Givi, S. Abdul Rashid, F. N. A. Aziz, M. A. M. Salleh. Influence of 15 and 80 nano-SiO2 particles addition on mechanical and physical properties of ternary blended concrete incorporating rice husk ash. J. Exp. Nanosci., 2013, 8, 1–18.
[22] S. L. Colston, D. O’Connor, P. Barnes. Functional micro-concrete: the incorporation of zeolites and inorganic nano-particles into cement microstructures. J. Mater. Sci. Lett., 2000, 19, 1085–1088.
[23] [23] Y. Qing, Z. Zenan, K. Deyu, C. Rongshen, Influence of nano-SiO2 addition on Properties of hardened cement paste as compared with silica fume. Construct. Build. Mater., 2007, 21, 539–545.
[24] K. L. Lin, W. C. Chang, D. F. Lin, H. L. Luo, M. C. Tsai. Effects of nano-SiO2 and different ash particle sizes on sludge ash–cement mortar. J. Environ. Manage., 2008, 88, 708–14.
[25] P. Jaishankar, K. Saravana Raja Mohan. Influence of nano particles in high performance concrete (HPC). Int. J. ChemTech Res., 2015, 8, 278–284.
[26] A. H. Shekaria, M. S. Razzaghi. Influence of nano particles on durability and mechanical properties of high performance concrete. Proc. Eng., 2011, 14, 3036–3041.
[27] Magdy A. El-Yamani, Ahmed Serrag, Taher Anwer Tawfik , Ghada M. Abd El Hafez. " Enhancing Physical and Mechanical Properties of Cement Based Morters and Corrosion Resistance of Reinforcing Steel using Nano - SiO_2. International Journal of Engineering Research & Technology (IJERT)., 2015, 4(3), 1126-1136.
[28] K. Sololev, M. F. Guti_errez. How nanotechnology can change the concrete world. Am. Ceram. Soc. Bull., 2010, 84, 10–14.
[29] C. L. D. Castro, B. S. Mitchell. (Ed: M.-I. Baraton) Nanoparticles from Mechanical Attrition, Synthesis, Functionalization and Surface Treatment of Nanoparticles., American Scientific, 2002, Chapter-1, 1–15.
[30] I. Borner, J. Eckert. Nanostructure formation and steady-state grain size of ball-milled iron powders. Mater. Sci. Eng. A., 1997, 226–228, 541–545.
[31] A. M. Fadzil, M. S. M. Norhasri, M. S. Hamidah, M. R. Zaidi, J. M. Faizal. Alteration of nano metakaolin for ultra high performance concrete. (Eds.: Z. Ismail, R. Hassan, M. Yusoff, N. Mohd Amin, M. Arshad Fadzil), InCIEC. Springer Science & Business Media Singapore, 2014, 887–894. doi:10.1007/978-981-4585-02-6_76.
[32] Li H, Xiao H-G, Yuan J, Ou J. Microstructure of cement mortar with nanoparticles. Composites 2004;35:185–9.
[33] Ali Heidari, Davoud Tavakoli, " A study of the mechanical properties of ground ceramic powder concrete incorporating nano-SiO_2 particles", Construction and Building Materials, 38 (2013), 255–264.
[34] J. Esmaeili, K. Andalibi. Investigation of the effects of nano-silica on the properties of concrete in comparison with micro-silica. Int. J. Nano Dimens., 2013, 3, 321–328.
[35] Taher A. Tawfik, Magdy A. Abd EL-Aziz, S. Abd El-Aleem and A. Serag Faried, " Influence of nanoparticles on mechanical and nondestructive properties of high-performance concrete", JOURNAL OF THE CHINESE ADVANCED MATERIALS SOCIETY, (2018), https://doi.org/10.1080/22243682.2018.1489303
[36] E. Ghafari, H. Costa, E. Julio, A. Portugal, L. Dur~aes. The effect of nanosilica addition on flowability, strength and transport properties of ultra high performance concrete. Mater. Des., 2014, 59, 1–9.