ISSN: 2277-3754
ISO 9001:2008 Certified
International Journal of Engineering and Innovative Technology (IJEIT)
Volume 7, Issue 1, July 2017

Effect of Elevated Temperature on Mechanical Properties of Nano Materials Concrete

Mohamed Amin Sherif
Civil Construction Dept., Faculty of Industrial Education/ Suez University, Suez, Egypt

***Abstract:** The current paper aims to investigate the effect of elevated temperature on compressive and flexural strengths of concrete containing nano materials. Specimens of twenty-four different concrete mixes with different intended compressive and flexural strengths were prepared and after 28 days the strengths were obtained at the room temperature (22^{o}C) and elevated temperatures. The research investigates the effect of elevated temperature degree (200 ^{o}C, 400 ^{o}C, and 600 ^{o}C) for an exposure period equals 120 minutes on the concrete compressive and flexural strength. The studied mixes reflect the key variables considered in the current study which are; the cement content, the silica fume percentage, nano materials type, and nano materials percentage. Two types of nano materials (nano-silica (NS) and nano-clay (NC) with five percentages (1, 2, 3, 4, and 5%) per type were adopted in this study. The results showed that using nano materials in concrete mixes increased the residual compressive and flexural strength after exposure to elevated temperatures. The results showed that the addition of nano materials to concrete mixes improves the performance of the produced blended concrete when exposed to elevated temperatures up to 200 ^{o}C. In general, the reduction in the compressive and flexural strength due to the exposure to elevated temperatures decreased at the nano materials percentage increased. Also, it was shown that the occurred reduction in the concrete compressive and flexural strength was increased in mixtures containing 450 Kg/m^3 than those of containing 350 Kg/m^3. In addition, it was shown that specimens of mixes of nano-clay improved the compressive and flexural strength to elevated temperature than of mixes with nano-silica.*

Keywords: **Nano Silica, Nano Clay, Silica Fume, High Strength Concrete, Compressive Strength, Flexural Strength, Elevated Temperature.**

I. INTRODUCTION

Concrete containing mineral admixtures is used extensively throughout the world for their good performance and for ecological and economic reason. The most common cementitious materials that are used as concrete constituents, in addition to Portland cement, are fly ash ground granulated blast furnace slag, silica fume and rice husk ash. They save energy, conserve resources and have many technical benefits [1-2].Fire resistance of concrete is highly dependent on its constituent materials, particularly the pozzolans. The effect of high temperature on concrete containing fly ash or natural pozzolans has not been investigated in detail. Researchers and investigators differ in their opinion regarding the changes in the properties of concretes, particularly in the range of 100–300 ˚C. Whereas for temperature above 300 ˚C, there is uniformity in opinion concerning a decrease in mechanical characteristics[3–4].However, strength reductions which have been reported in the literature reveal significant quantitative differences due to the variety of high temperature condition tested, and the variety of constituent materials of concrete used. It is recognized that the behavior of concrete subjected to high temperatures is a result of many factors such as heating rate, peak temperatures, dehydration of C–S–H gel, phase transformations, and thermal incompatibility between aggregates and cement paste [5].Aly *et al.* [6] presented a laboratory study of the properties of nano-clay/waste-glasspowdercement composites. They investigated the microstructure, fracture energy, compressive and flexural properties of cement mortars containing waste-glass powder as acement replacement with and without nano-clay and compared these properties with plain matrix. The results showed that incorporation of glass powder had a positive effect on the mechanical properties of cement mortars after 28 days of hydration. Also, the results revealed that the mechanical properties of the cement mortar with a hybrid combination of glass powder and nano-clay were all higher than those of plain mortar and with glass powder after 28 days of hydration.Fan *et al.* [7] investigated the effects of NKC on the freezing and thawing (F–T) behavior of concrete. A rapid freeze–thaw Cabinet was used to measure the resistance of concrete to deterioration caused by repeated F–T actions. Also, they measured the properties of concrete specimens in terms of pore structure, mass, electrical resistivity, chloride diffusion coefficient, compressive strength and dynamic modulus of elasticity. The experimental results and visual inspection revealed that the mixes incorporating NKC had improved F–T resistivity values, compared to control mix. The samples with 5% NKC exhibited the highest compressive strength, chloride diffusion resistivity, relative dynamic modulus of elasticity and the highest electrical resistivity after 125 F–T cycles. Nanoclay particles have shown promise in enhancing the mechanical performance, the resistanceto chloride penetration, and the self-compacting properties of concrete and in reducing permeability and shrinkage [8-9].Ibrahim *et al.* [10] studied the effect of using colloidal NS as a partial replacement of cement in combined with the use of FA on the fire resistance of mortar specimen's subjected to high temperatures of 400 and 700˚C. The heating rate was 9˚C/min and the specimens were held at these temperatures for 2 hours then they were left to cool to room temperature at approximately the same rate and the flexure and compression tests were carried out. The samples were also evaluated by scanning electron microscopy (SEM) and X-ray diffraction (XRD) tests; and their porosity were determined using BET (Brunauer, Emmett and Teller) technique to study the specimens' behavior after exposure to high temperatures. Where, the crystalline nature, CH, calcium silicate (CS) and silica peaks appear clearly in the XRD diagrams, while amorphous materials such as CSH cannot be directly detected by this technique. The compressive and flexural strength results showed that the mortars had stable micro-structure state after exposure to temperatures up to 400˚C, while exposure to temperatures greater than 600˚C decomposed the hydration products to decompose considerably that resulted in an extreme deterioration of the material's strength. The addition of NS increased the compressive strength of mortar subject to 400˚C temperature, but at 700˚C the compressive strength was decreased with increasingthe NS content. They also reported that after exposure to elevated temperature, the pore size distribution was considerably decreased with the addition of NS.Heikal *et al.* [11] studied the fire resistance of composite cement pastes containing 0, 1, 2, 4, 6% NS for specimens cured for 28 days. The specimens were subjected to heat at 250, 450, 600, 800 and 1000˚C with rate of heating of 3˚C/min for 3 hours soaking time then cooled to room temperature in the furnace switched off. The compressive strength of cement pastes was increased with NS content up to 4%. The compressive strengths of 4% NS paste were the higher values at all temperature up to 1000 ˚C, thus it had the higher resistance to fire than all composite cement pastes. Also, it had the highest values of bulk density. Increasing NS to 6% had a bad effect and reversed the results. Bastami *et al.* [12] studied the effect of elevated temperature on the compressive and tensile strength, spalling and mass loss of SF concrete. Eight mixes had 500 kg/m^3 cement content modified with 6 and 12% SF in combined with 0, 1.5, 3 and 4.5 % of NS as replacement every percentage of SF. The mechanical properties of specimens were measured by heating concrete samples to 400, 600 and 800˚C at a rate of 20˚C/min. The result showed that addition of up to 4.5% NS increased the residual compressive and tensile strengths and decreased the mass. There was no visible effect on the surface of heated specimens up to 400 ˚C and the mass loss was minimum because the evaporation of water takes place at higher temperature. Large cracks and partial spalling were observed when the temperature reached 600˚C and the aggregates decomposed and lost their integrity as the temperature reached 800˚C. The properties of concrete after exposure to fire were primarily assessed by observing the change of color of concrete. All specimens heated to greater than 400˚C experienced spalling and mass loss. The spalling ranged from insignificant aggregate spalling to large portions of specimens being blown off with explosive force. The effect of SF and NS on mass loss was not easily discerned because the decrease in permeability and increase in tensile strength had opposite effects on spalling and mass loss. As permeability decreased, spalling increased; however, when tensile strength increased, mass loss decreased. The compressive strength of specimens decreased significantly at 800 ˚C, the residual strength was about 25%. All heated specimens deteriorated above 600˚C. The decrease in compressive strength was greater for concrete containing NS and heated to 600-800˚C. The addition of NS was more effective than SF for increasing the residual compressive and tensile strength of heated specimens. The presence of NS improved the compressive and tensile strength of concrete to prevent crack extension and strength reduction. Since human safety in case of fire is one of the major considerations in the design of buildings, it is extremely necessary to have a complete knowledge about the behavior of all construction materials before using them in the structural elements.

II. EXPERIMENTALWORK

A. Materials

a. Cement

In this study, CEM I 42.5 N. Testing of cement was carried out as the Egyptian Standard Specifications ESS 4756-1/2009 [13], with the specific gravity of 3.15 was used. The properties shown in Table (1).

Table 1 Chemical Composition of Materials

Oxide Composition	CEMI By Mass %	NS By Mass %	NC By Mass %
Silicon dioxide (SiO_2)	20.20	99.5	61.24
Aluminum oxide (Al_2O_3)	6.00	-	20.89
Ferric oxide (Fe_2O_3)	3.30	-	1.06
Calcium oxide (CaO)	62.70	-	0.16
Magnesium oxide (MgO)	2.00	-	0.22
Sulphur trioxide (SO_3)	2.20	-	0.17
Potassium oxide (K_2O)	0.83	-	1.61
Titanium dioxide (TiO_2)	-	-	0.70
Sodium oxide (Na_2O)	0.76	-	0.71
Loss on Ignition (LOI)	1.70	-	13.12

b. Aggregates

Fine aggregate used in this experimental work was natural siliceous sand, clean and rounded fine aggregate with a specific gravity of 2.65, a bulk unit weight of 1675 Kg/m3, and a void percentage 36.8%, and fineness modulus of 2.92. The coarse aggregate used was local crushed limestone (dolomite) with a specific gravity of 2.66, a bulk unit weight of 1618 Kg/m3, a void percentage 39.2%, fineness modulus of 6.35, and maximum nominal size of 13 mm, according to the requirement of ESS 1109/2002 [14].

c. Silica fume

In this research, silica fume (SF) waslocally produced in Egypt having a silica content of 96.5%, a specific gravity of 2.15, a color of light gray, a bulk unit weight of 392 Kg/m3 and specific surface area of 20000 cm2/gm was used.

d. Superplasticizer

In order toachieve superior workability and required flowabilityof the fresh concrete, there is a commercially availablesuperplasticizer.Itmeetsthe requirements for superplasticizer according to ASTM-C-494 Type G and BS EN 934 part 2: 2001, with a specific gravity of 1.08 and a color of clear liquid.

e. Nano Silica

The nano-silica used in this research is powder type. The chemical and physical properties are given in Table (1) and Table (2) respectively.

f. NanoClay

The nano-clay used in this work is montmorillonite clay (sodium calcium aluminum silicate). The properties of nanoclay shown in Tables (1) and (2). Figure (1) show TEM (Transmission Scanning Election Microscopy) micrographs of nano clay particles.

Table 2 The physical properties of Nano Silica and Nano Clay

properties	Test results	
	Nano Silica	Nano Clay
Form	powder	powder
Color	Colorless (White)	Light Cream
Formula	SiO_2	SiO_2
Density	2.2 - 2.6 g/mL at 25 °C (77 °F)	1.9 (gm/cm^3)
Surface Area	-	330 (m^2/gm)

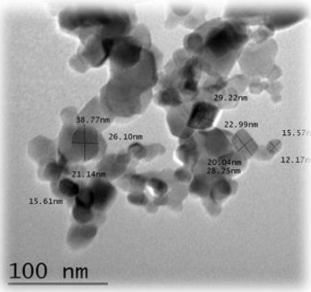

Fig. 1 TEM Micrograph of NanoClay Particles

B. Mix proportion

To achieve the objectives of this work, two groups of concrete (fc= 56 to 110 MPa) with a total numbers of 24 mixes were prepared and investigated. Table (3) illustrates the mix design of all mixes. The mixes were divided into two groups representing the key variables in the current study. The first group with 350 Kg/m^3 (mixes 1 to 12), mix 1 possesses neither silica fume nor nano-materials, while the mixes from 2 to 7 contains silica fume with a percentage of 15% as addition to cement and nano- silica with percentages 0, 1, 2, 3, 4 and 5%, respectively, and the mixes from 8 to 12 contains silica fume with a percentage of 15% as addition to cement and nano-clay with percentages 1, 2, 3, 4 and 5%, respectively. The second group with 450 Kg/m^3 (mixes 13 to 24), mix 13 possesses neither silica fume nor nano-materials, while the mixes from 14 to 19 contains silica fume with a percentage of 15% as addition to cement and nano- silica with percentages 0, 1, 2, 3, 4 and 5%, respectively, and the mixes from 20 to 24 contains silica fume with a percentage of 15% as addition to cement and nano-clay with percentages 1, 2, 3, 4 and 5%, respectively.

C. Testing Procedure

The compressive and flexural strength tests were performed in accordance with ASTM C109 [15], and ASTM C78 [16], respectively, cubic specimens of 100×100×100 mm for compressive strength and prism specimens of 100×100×500 mm for flexural strength was used.

D. Exposure to Elevated Temperature

For each of the presented mixes in Table (3), three samples per batch were tested and the average strength is reported, and cured in tap water for 28 days. At the age of 28 days, the specimens were heated in an electric furnace at 200^oC, 400 ^oC, and 600^oC. Each temperature was maintained for 2 hours to achieve the thermal steady state. Then the compressive strength and flexural strength after 28 days was obtained at ambient temperature and after exposed to elevated temperatures of 200 ^oC, 400 ^oC, and 600 ^oC for 2 hours. Electric furnaces were used for heating process, see figure (2).

Fig. 2 Electric Furnace of High Temperature

III. RESULTS AND DISCUSSION

A. Compressive Strength

The compressive strengths after 28 days of all mixes were determined at roomtemperature and after exposure to elevated temperature of 200 °C, 400 °C, and 600 °C for 2 hours. Comparisons between the results can demonstrate the effect of elevated temperatures on mixes with or without nano materials. Tables (4) and (5) listed the values of compressive strengths and relative of control specimens (at room temperature) and the residual strength after exposure to 200 °C, 400 °C, and 600 °C for also 2 hours. There were no visible cracks on the surface of specimens heated at 200 ^oC, whereas at 400^oC the surface pitting of aggregate interface were observed, large cracks and partial spalling of concrete was observed at 600 ^oC. The compressive strength of thermally treated concrete specimens after cooling was determined. The results shown in Table (4) and figures (3 to 8) indicate the residual compressive strength of each specimen at different elevated temperatures. From the perspective of residual compressive strength of concrete, the heating conditions can be divided into two regions as 22 - 200 ^oC, and 200 - 600 ^oC. Distinct patterns of strength loss followed by a gain were observed in first region and then subsequent sharp loss in the second region. The silica flour concrete showed a higher increase in compressive strength in 22 - 200 ^oC range than control concrete. This increase may be due to the hydrothermal interaction of the silica fume and nano materials particles as a result of temperature rise with the liberated free lime during hydration reaction. The control specimen's showedaslowincrease in compressive strength in 22 - 200 °C range followed by sharp loss in strength. The observed increase in compressive strength of the control concrete may be due to further hydration of unhydrated cement grains as a result of internal autoclaving effect. However the increase in compressive strength of blended concrete containing15 % silica fume and nano materials was mainly due to pozzolanic reaction; which led to the formation of additional amount of hydration products. At high temperatures, especially above 22 °C, the thermal effect might cause water migration whereas dehydration of moisture supply from outside is insufficient. Internal stress and thus micro and macrocracks are generated due to the heterogeneous volume dilatations of ingredients and the buildup of vapor in the pores. Therefore, at higher temperature, especially above 200 °C, the observed decrease in compressive strength of blended concrete containing 15 % silica fume and nano materials may be due to internal thermal stress generated around pores which generate microcracks.In general, as indicated from Tables (4) and (5), increasing the cement content increased the compressive strength of concrete mixtures at ambient

temperatures or those subjected to elevated temperatures of 200 °C, 400 °C, and 600 °C for 2 hours. In mixes without silica fume or nano materials, increasing the cement content from 350 kg/m^3 to 450 kg/m^3 increased the compressive strength of concrete mixtures subjected to temperature 600 °C after 28 days from 33.5 MPa to 39.1 MPa see Table (4). On the other hand, the reduction in compressive strength due to the exposure to 600 °C for 2 hours increased from 40.0% (cement content = 350 kg/m^3) to 43.2% (cement content = 450 kg/m^3).

Table 3 Proportions of Concrete Mixes

Group	Mix Code	CEM1	F.Agg. Sand	C.Agg.		Silica Fume	Super Plasticizer	W/Cm	Nano Particles	
									NS	NC
		Kg/m^3	%	Type	%	%	%		%	%
A	M1	350	40	Dolomite	60	0	3	0.25	0	0
	M2	350	40	Dolomite	60	15	3	0.25	0	0
	M3	350	40	Dolomite	60	15	3	0.25	1	0
	M4	350	40	Dolomite	60	15	3	0.25	2	0
	M5	350	40	Dolomite	60	15	3	0.25	3	0
	M6	350	40	Dolomite	60	15	3	0.25	4	0
	M7	350	40	Dolomite	60	15	3	0.25	5	0
	M8	350	40	Dolomite	60	15	3	0.25	0	1
	M9	350	40	Dolomite	60	15	3	0.25	0	2
	M10	350	40	Dolomite	60	15	3	0.25	0	3
	M11	350	40	Dolomite	60	15	3	0.25	0	4
	M12	350	40	Dolomite	60	15	3	0.25	0	5
B	M13	450	40	Dolomite	60	0	3	0.25	0	0
	M14	450	40	Dolomite	60	15	3	0.25	0	0
	M15	450	40	Dolomite	60	15	3	0.25	1	0
	M16	450	40	Dolomite	60	15	3	0.25	2	0
	M17	450	40	Dolomite	60	15	3	0.25	3	0
	M18	450	40	Dolomite	60	15	3	0.25	4	0
	M19	450	40	Dolomite	60	15	3	0.25	5	0
	M20	450	40	Dolomite	60	15	3	0.25	0	1
	M21	450	40	Dolomite	60	15	3	0.25	0	2
	M22	450	40	Dolomite	60	15	3	0.25	0	3
	M23	450	40	Dolomite	60	15	3	0.25	0	4
	M24	450	40	Dolomite	60	15	3	0.25	0	5

Table 4 Compressive and Flexural Strengths of the Heated and Unheated Test Concrete Specimens after 28 Days

Mix Code	Cement Content	SF	Nano		Compressive Strength (MPa)				Flexural Strength (MPa)			
			NS	NC								
	Kg/m^3	%	%	%	At 22^{o}C	At 200^{o}C	At 400^{o}C	At 600^{o}C	At 22^{o}C	At 200^{o}C	At 400^{o}C	At 600^{o}C
M1	350	0	0	0	55.8	57.4	50.2	33.5	9.2	9.5	8.2	5.8
M2	350	15	0	0	71.5	73.2	55.8	28.9	11.5	11.7	8.6	5.2
M3	350	15	1	0	79.3	81.3	65.8	36.2	12.7	13.0	10.1	6.3
M4	350	15	2	0	82.8	85.0	69.5	38.8	13.1	13.4	10.5	6.6
M5	350	15	3	0	85.7	88.0	72.4	40.7	13.7	14.1	11.1	7.0
M6	350	15	4	0	88.9	91.4	75.5	42.8	14.1	14.6	11.5	7.3
M7	350	15	5	0	85.5	88.1	73.5	41.9	13.6	14.1	11.2	7.2
M8	350	15	0	1	73.7	76.0	61.9	35.0	11.8	12.1	9.6	6.1
M9	350	15	0	2	76.2	78.7	64.8	36.9	12.2	12.5	10.1	6.4
M10	350	15	0	3	78.8	81.5	67.7	39.3	12.6	13.0	10.5	6.7
M11	350	15	0	4	80.5	83.3	70.0	41.0	12.8	13.3	10.8	6.9
M12	350	15	0	5	78.5	81.4	69.2	40.7	12.5	13.0	10.6	6.8
M13	450	0	0	0	68.8	70.6	60.6	39.1	11.1	11.4	9.7	6.7
M14	450	15	0	0	88.5	90.2	62.0	32.0	14.1	14.2	9.9	5.7
M15	450	15	1	0	98.6	100.5	74.0	41.3	15.3	15.5	11.4	6.8
M16	450	15	2	0	102.1	104.3	77.1	43.3	15.8	16.1	11.9	7.1
M17	450	15	3	0	106.2	108.5	80.8	45.8	16.5	16.9	12.5	7.5
M18	450	15	4	0	109.8	112.3	83.9	48.2	17.3	17.8	13.3	8.0
M19	450	15	5	0	106.7	109.4	82.2	47.5	16.6	17.1	12.9	7.8
M20	450	15	0	1	96.4	98.5	73.3	42.4	14.9	15.2	11.3	6.9
M21	450	15	0	2	98.1	100.5	75.9	44.2	15.3	15.6	11.8	7.2
M22	450	15	0	3	100.1	102.6	78.0	46.1	15.5	15.9	12.1	7.4
M23	450	15	0	4	103.2	106.0	81.3	47.9	16.0	16.5	12.6	7.8
M24	450	15	0	5	99.9	102.7	80.1	47.0	15.4	15.9	12.3	7.6

This means that, the using of cement content equals 450 kg/m^3 instead of an increase in the reduction in the compressive strength of concrete samples subjected to temperature 600 °C which can be attributed to the dense internal structure and low permeability of mixes of 450 kg/m^3 cement content.The effects of using silica fume and nano materials as additions to cement on the compressive strength of the similar mixes at elevated temperature 200 °C, 400 °C, and 600 °C after 28 days are also shown in Table (4) and Figures (3 to 6). In general, increasing the percentage of silica fume as addition to the cement content (up to 15%) decreased the compressive strength at the considered elevated temperatures. While, the addition of nano materials (NS and NC) improve the compressive strength of mixes subjected to different temperatures for the two cement contents 350 kg/m^3 and 450 kg/m^3, see Figures (3 to 6). Moreover, in mixes with 15% silica fume and without nano materials were observed the reduction in compressive strength due to the exposure to 600 °C for 2 hours equals about 59.6% for cement content = 350 kg/m^3 and 63.8% for cement content = 450 kg/m^3, see Table (5). This observation can be referred to the low permeability and high brittleness of this mixes. The dense internal structures of these mixes prevent the vapor to discharge at high temperatures. In addition, the used high content of silica fume may contribute in this phenomenon. The crystal shape transformation of SiO_2 resulted in increases in their volume when heating and exploding can be occurred. In mixes containing 15% silica fume and 5% NS achieved improvement in the reduction of compressive strength at 600 °C for 2 hours equals about 51.0% for cement content=350 kg/m^3 and 55.5% for cement content=450 kg/m^3, see Table (5) and Figures (3 and 5).

Table 5 Relative Compressive and Flexural Strengths of Concrete Specimens after 28 Days

Mix Code	Cement Content	SF	Nano		Compressive Strength (%)				Flexural Strength (%)			
	Kg/m^3	%	NS %	NC %	At 22°C	At 200°C	At 400°C	At 600°C	At 22°C	At 200°C	At 400°C	At 600°C
M1	350	0	0	0	100	102.9	90.0	60.0	100	103.3	89.1	63.0
M2	350	15	0	0	100	102.4	78.0	40.4	100	101.7	74.8	45.2
M3	350	15	1	0	100	102.5	83.0	45.7	100	102.3	79.5	49.6
M4	350	15	2	0	100	102.7	83.9	46.9	100	102.3	80.2	50.4
M5	350	15	3	0	100	102.7	84.5	47.5	100	102.9	81.0	51.1
M6	350	15	4	0	100	102.8	84.9	48.1	100	103.5	81.6	51.8
M7	350	15	5	0	100	103.0	86.0	49.0	100	103.7	82.4	52.9
M8	350	15	0	1	100	103.1	84.0	47.5	100	102.5	81.4	51.7
M9	350	15	0	2	100	103.3	85.0	48.4	100	102.5	82.8	52.5
M10	350	15	0	3	100	103.4	85.9	49.9	100	103.2	83.3	53.2
M11	350	15	0	4	100	103.5	87.0	50.9	100	103.9	84.4	53.9
M12	350	15	0	5	100	103.7	88.2	51.9	100	104.0	84.8	54.4
M13	450	0	0	0	100	102.6	88.1	56.8	100	102.7	87.4	60.4
M14	450	15	0	0	100	102.0	70.0	36.2	100	100.7	70.2	40.4
M15	450	15	1	0	100	102.0	75.1	41.9	100	101.3	74.5	44.4
M16	450	15	2	0	100	102.2	75.5	42.4	100	101.9	75.3	44.9
M17	450	15	3	0	100	102.2	76.1	43.1	100	102.4	75.8	45.5
M18	450	15	4	0	100	102.3	76.4	43.9	100	102.9	76.9	46.2
M19	450	15	5	0	100	102.5	77.0	44.5	100	103.0	77.7	47.0
M20	450	15	0	1	100	102.2	76.0	44.0	100	102.0	75.8	46.3
M21	450	15	0	2	100	102.4	77.4	45.1	100	102.0	77.1	47.1
M22	450	15	0	3	100	102.5	77.9	46.1	100	102.6	78.1	47.7
M23	450	15	0	4	100	102.7	78.8	46.4	100	103.1	78.8	48.8
M24	450	15	0	5	100	102.8	80.2	47.1	100	103.3	79.9	49.4

The reduction in compressive strength due to the exposure to 600 °C for 2 hours of mixes with 15% silica fume and 5% NC achieved about 48.1% for cement content=350 kg/m^3 and 52.9% for cement content=450 kg/m^3, as shown in Table (5) and Figures (4 and 6). On the other hand, the reduction in compressive strength due to the exposure to 600 °C for 2 hours of mixes with 15% SF+5% NS and 15% SF+5% NC increased to 8.6% and 8.3% about mix with silica fume only for 350 kg/m^3 cement respectively, and increased to 11.5% and 10.9% for 450 kg/m^3 cement respectively. The nano particles are more active for the cement hydration, which makes the cement matrix more homogeneous and compact so the pore structure is improved this compact structure starts losing its integrity beyond 600 °C in case of concrete caste by adding nano particles whereas spalling of concrete and loosing of integrity in case of normal concrete mixes starts at 400 °C , which indicates that the concrete containing nano particles are safe up to 600 °C and beyond which large crack formation and spalling of concrete starts.

B. Flexural Strength

The test results of flexural strength for24 different mixtures subjecting to different elevated temperatures of 200, 400, and 600 °C after 28 days of curing are shown in Table 4-5 and Figures (9 to 14). Figures (9 to 12) illustrates the flexural strength of concrete with and without nano materials exposed to elevated temperature up to 600 °C.

Evidently, the flexural strength of concrete decreases as the exposed temperature increases.The mixes with 15% silica fume and nano materials in concrete caused a stable flexural strength up to 200 °C followed by a sharp decrease.

In 15% silica fume concrete containing nano materials, the exposure to 400 °C led to further hydrothermal reaction of unhydrated cement grains and pozzolanic reaction of silica fume with calcium hydroxide liberated during the hydration process.

Furthermore, the decrease in flexural strength from 200 °C to 600 °C was due to the formation of microcracks. Also the reduction in flexural strength can be attributed to the driving out of free water and fraction water of hydration of concrete due to high temperatures.The results shown in Figures (9 to 14) indicated that the mix having silica fume and nano materials suffered significant loss in flexural strength at the temperature of 600 °C. The flexural strength for concrete mixes with 350 kg/m^3 cement was reduced by 54.8%, 47.1%, and 45.6% to using SF, NS, and NC respectively when they were heated to 600 °C. While the flexural strength for concrete mixes with 450 kg/m^3 cement was reduced by 59.6%, 53.0%, and 50.6% when subject to 600 °C. It is worthy of note that, the average loss in flexural strength of the SF concrete, is 6.6% and 9.0% higher than the loss in flexural strength of the NS and NC concrete respectively, 450 kg/m^3 cement when subject to 600 °C as shown in Table 5. It can then be said that, NC concrete can perform better in flexure under elevated temperature when compared to the NS concrete.

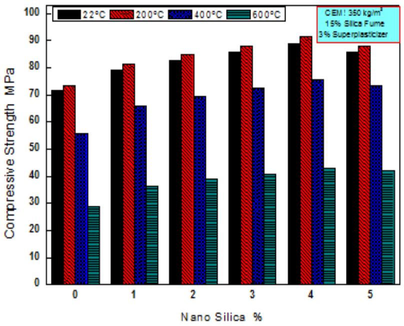

Fig. 3 Effect of nanosilica on the compressive strength of mixes with 350 kg/m^3 cement at different Temperatures

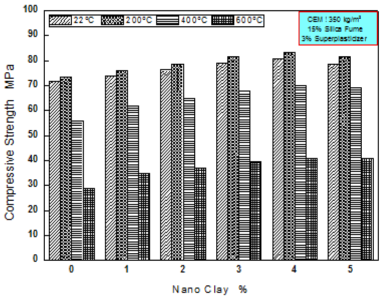

Fig. 4 Effect of nanoclay on the compressive strength of mixes with 350 kg/m^3 cement at different Temperatures

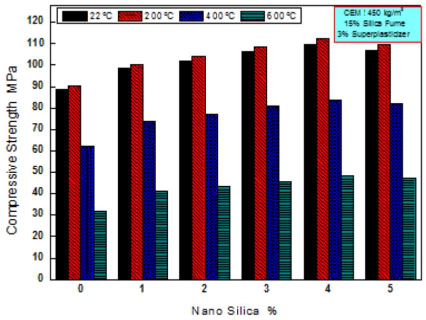

Fig. 5 Effect of nanosilica on the compressive strength of mixes containing450 kg/m^3 cement subjected to different Temperatures

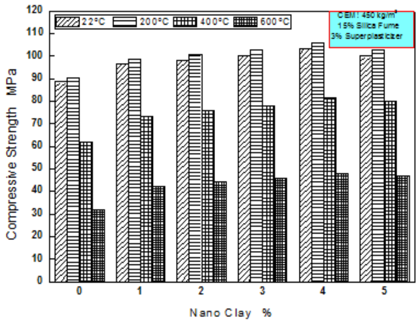

Fig. 6 Effect of nanoclay on the compressive strength of mixes containing450 kg/m^3 cement subjected to different Temperatures

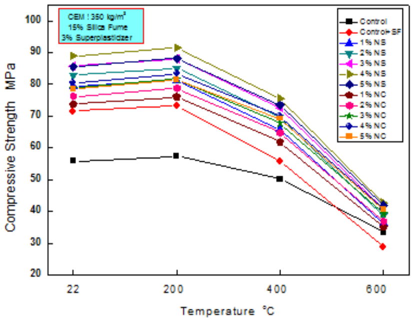

Fig. 7 Effect of elevated temperature on the compressive strength at 28 days of mixes with cement content 350 kg/m^3

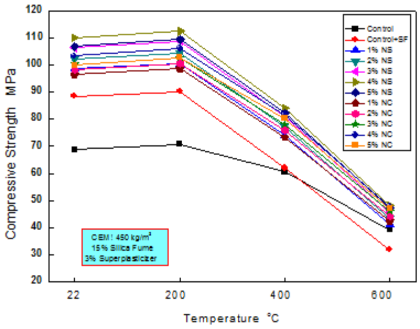

Fig. 8 Effect of elevated temperature on the compressive strength at 28 days of mixes with cement content 450 kg/m^3

DOI:10.17605/OSF.IO/VH48E

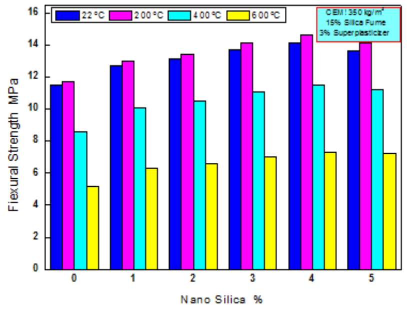

Fig. 9 Effect of nanosilica on the flexural strength of mixes with 350 kg/m^3 cement at different Temperatures

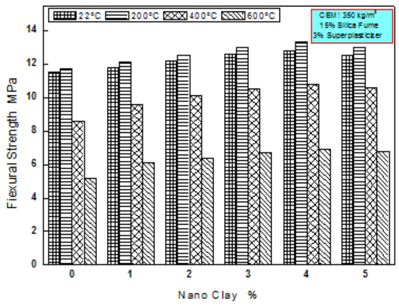

Fig. 10 Effect of nanoclay on the flexural strength of mixes with 350 kg/m^3 cement at different Temperatures

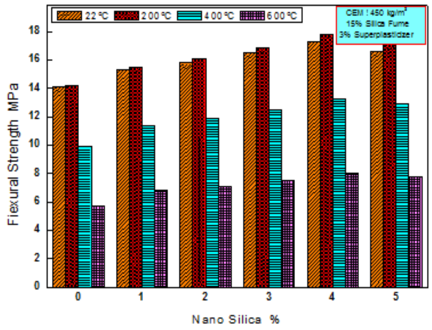

Fig. 11 Effect of nanosilica on the flexural strength of mixes containing450 kg/m^{3}cement subjected to different Temperatures

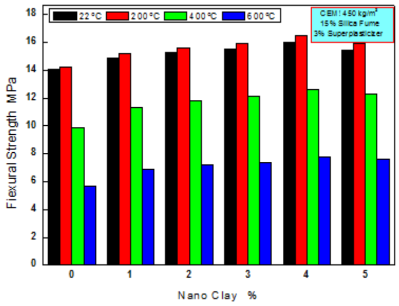

Fig. 12 Effect of nanoclay on the flexural strength of mixes containing 450 kg/m^3 cement subjected to different Temperatures

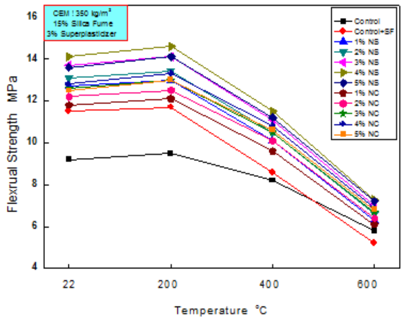

Fig. 13 Effect of elevated temperature on the flexural strength at 28 days of mixes with cement content 350 kg/m^3

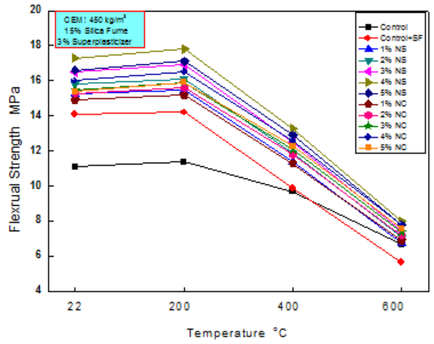

Fig. 14 Effect of elevated temperature on the flexural strength at 28 days of mixes with cement content 450 kg/m^3

IV.CONCLUSION

In this research, the experimental work have been performed to investigate the residual compressive and flexural strengths of nano materials concrete subjected to elevated temperatures ranging from 200 to 600 °C for 2 hours. Based on the experimental results presented in this research, the following conclusions may be obtained from this study:

1. Increasing the cement content increases the initial strength of concrete without SF or nano materials but decreases the residual strength values after heating as the temperature increased.
2. The reduction in compressive strength due to the exposure to 600 °C for 2 hours increased from 40.0% (cement content=350 kg/m^3) to 43.2% (cement content=450 kg/m^3).
3. The nano materials (NS and NC) enhance the mechanical properties of concrete at room temperature up to 200 °C. Increasing the temperature decreasetheresidual compressive and flexural strengths.
4. The maximum compressive and flexural strengths loss was found in SF specimens. The SF is more vulnerable to high temperature and loss in strengths, mass and quality was found to be more extensive in this type of concrete.
5. The reduction in compressive strength due to the exposure to 600 °C for 2 hours of mixes with 15% SF+5% NS and 15% SF+5% NC increased to 8.6% and 8.3% about mix with silica fume only for 350 kg/m^3 cement respectively, and increased to 11.5% and 10.9% for 450 kg/m^3 cement respectively.

6. The average loss in flexural strength of the SF concrete is 6.6% and 9.0% higher than the loss in flexural strength of the NS and NC concrete respectively, 450 kg/m^3 cement when subject to 600 ^{o}C.
7. The specimens of mixes of nanoclay improved the compressive and flexural strength to elevated temperature than of mixes with nano-silica.

REFERENCES

[1]. O. Arioz, “Effect of elevated temperature on properties of concrete, “Fire Safety Journal, 42 (2007), pp. 516-522.

[2]. M. S. Morsy, S. H. Alsayed and M. Aqel “Effect of Elevate Temperature on Mechanical Properties and Microstructure of Silica Flour Concrete” International Journal of Civil & Environmental Engineering IJCEE-IJENS Vol: 10 No: 01(2010), pp. 1-6.

[3]. C. He, E. Makavicky and B. Osback, “Thermal stability and pozzolanic activity of calcined kaolin. Appl. Clay Sci. 9 (1994), pp. 165–187.

[4]. A.M. Dunster, J.R. Parsonage and M.J.K. Thomas, “Pozzolanic reaction of metakaolinite and its effects on Portland cement hydration. J. Mater. Sci. 28 (1993), pp. 1345–1351.

[5]. W. Sha and B. Pereira, “Differential scanning calorimetry study of ordinary Portland cement paste containing metakaolin and theoretical approach of metakaolin activity.," Cement Concrete Compos. 23 (2001), pp. 455–461.

[6]. Aly, M., Hashmi, M. S. J., Olabi, A. G., Messeiry, M. and Hussain, A. I., "Effect of Nano Clay Particles on Mechanical, Thermal and Physical Behaviors of Waste-Glass Cement Mortars", Materials Science and Engineering: A 528 (2011), no. 27, 7991-7998.

[7]. Nazari, A. H. and Riahi, S., "Effects of CuO Nanoparticles on Microstructure, Physical, Mechanical and Thermal Properties of Self-Compacting Cementitious Composites", Journal of Materials Science & Technology 27 (2011), no. 1, 81-92.

[8]. Chang, T.-P., J.-Y. Shih, K.-M. Yang and T.-C. Hsiao. "MaterialProperties of Portland cement Paste with Nano-Montmorillonite", Journal of Material Science, Vol. 42, No. 17, 2007, pp. 7478–7487.

[9]. Sayed Abd El-Baky, Sameh Yehia, Enas A., and Ibrahim S., "Effect of Nano-Clay on The Mechanical Properties of Fresh and Hardened Cement Mortar Comparing with Nano-Silica", The Second International Conference on Materials, Energy and Environments (ICMEE), August 08-09, 2013, Yokohama, Japan.

[10]. Ibrahim R.K., Hamid R. and Taha M.R., "Fire resistance of high volume fly ash mortars with nan silica addition", Construction and Building Materials, vol. 36, 2012, pp. 779-786.

[11]. Heikal M., Ali A.I., Ismail M.N. and Ibrahim S.A.N.S., "Behavior of composite cement pastes containing silica nano-particles at elevated temperature", Construction and Building Materials,vol. 70, No. 0, 2014,pp. 339-350.

[12]. Bastami M., Baghbadrani M. and Aslani F., "Performance of nano-Silica modified high strength concrete at elevated temperatures", Construction and Building Materials, vol. 68, No. 0, 2014, pp. 402-408.

[13]. ESS (4756-1/2009) Egyptian Standard Specifications, cement physical and mechanical test.

[14]. ESS (1109/2002) Egyptian Standard Specifications, concrete aggregates from natural sources.

[15]. ASTM C 109/ C 109M-12, “Standard Test Method for Compressive Strength of Hydraulic Cement mortars”.

[16]. ASTM C78 / C78M - 16, “Standard Test Method for Flexural Strength of Concrete”.