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Flowability and Durability of High Strength Concrete Incorporated with Different Nano or Micro or Recycled Material

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Abstract:

The purpose of this study is to investigate the effect on workability and durability of concrete by partial replacement of cement with nano SiO2 and nano CaCO3 particles, micro SiO2, micro CaCO3, recycled silica gel (beads and powder) and limestone. All replacements were used with four different contents of 1%, 2%, 3% and 4% by weight. The results showed that the workability of fresh concrete was decreased by increasing the content of nano particles and micro particles. It is concluded that partial replacement of cement with nano or micro and recycled SiO2 and CaCO3 decreases the water absorption of concrete by increasing replacements content.

Keywords: *Nano concrete, workability of concrete, durability of concrete, green concrete*

1. Introduction

The cement industry is considered to be one of the most energy consuming industries, which is also responsible for approximately 6-7% of the global man-made CO2 emissions annually. Accordingly, there is a great demand to minimize the quantity of cement used in the construction industry. In this context, supplementary cementing materials (SCMs) with pozzolanic or hydraulic properties have been particularly attractive compounds or mixtures which partially replace ordinary Portland cement required for a cement-based [1]. Due to the complex structure of concrete and its heterogeneity at all length scales, and the recent innovations in nanotechnology, nano modification of cement-based materials has generated much research interest [2]. In this work the effect of nano SiO2 and CaCO3, micro SiO2 and CaCO3 and recycled silica gel and limestone as replacements of cement on the flowability and water absrorption in high strength concrete mixes were studied.

Zemei et.al. [3] found that increasing of nano SiO2 and CaCO3 content decreased the porosity , also the slump flow of ultra-high strength concrete was decreased and good improvement in permeability was recognized by increasing the nanoparticles content. Peng zang et,al.[4]studied the effect of nano SiO2 on durability of high performance concrete. It is shown that in general the incorporation of nano SiO2 particles significantly improves the durability of high performance concrete though the flowability of fresh concrete was decreased by usage of nano SiO2.

Faiz U.A. et,al [5] investigated the effect of nano CaCO3 on durability of high volume fly ash concrete. Results showed that mixes with nano particles have lower volume of permeable voids, porosity, higher resistance to water sorptivity and also changed the formation of hydration product. Wengui Li et,al, [6]found that the effect of nano SiO2 and CaCO3 when added to concrete act as an effective filling materials which reduce porous area and accelerated the cement hydration process by improve the water absorption resistance. Workability decreased with increasing the content of nano particles.

2. Experimental details

2-1 Materials

Ordinary Portland Cement Type I, named Karasta, which are indicated that the cement is conformed to Iraqi specifications (I.Q.S.) No. 5/1984[7], tables (1) and (2) indicated the chemical and physical properties of the cement. Locally available natural sand for concrete mixes used as fine aggregate. Crushed gravel maximum size of 14mm and specific gravity of 2.8g/cm³ was used as coarse aggregate, tables (2) and (3) showed the sieving analysis of sand and gravel respectively. Nano SiO2, nano CaCO3, micro SiO2, micro CaCO3, recycled silica gel and lime stone from building debris were used as concrete admixture in this work figure (1) showed the XRD spectra for each replacement.

2-2Mix Proportion

In absorption and flowablity specimen's mixes, preparation the target design strength of 50, 70 MPa were designed according to British mix design method BS5328. Part 2:1991[8], forty-one types of concrete mixes are implemented in this study. The fixed parameters for all mixes are: water/cementitious, coarse and fine aggregate fractions, and superplasticizer contents. Mixes details and symbols can be seen in Table (5).

2-3Tests

2-3-1 Water absorption test

The water absorption was conducted according to ASTM C642 [9], the water absorption test is carried out using (50x100 mm) cylinder specimens, testing procedure included removing the specimens from tap water at 28 days' age and placing it in an oven with a temperature set of 105 C° for about 24 hours. After that, the oven is switched off and the specimens stilled in it for a specific period to be cooled then lifted from the oven and weighed. Thereafter, it returned to the oven and heated again as mentioned above. The process is repeated until the decrease in mass between two successive values becomes equal or less than 0.5%. The final dried mass is recorded. Then the oven-dried specimens placed in tap water for about 24 hours then removed from water and weighed. After that, they immersed in tap water for additional 24 hours, then removed and weighed. and the average water absorption of two samples was recorded and considered.

Absorption after immersion,% = $\frac{B-A}{A}x100$

Where:

A = mass of oven-/dried sample in air, gm.

B = mass of saturated surface-dry sample in air after immersion, gm.

2-3-2 Flow slump test

A slump cone with flow table, the flow table is wetted, and the cone is placed in the center of the flow table and filled with fresh concrete in two equal layers. Each layer is tamped 10 times with a tamping rod. wait 30 seconds before lifting the cone. then cone is lifted, allowing the concrete to flow, the flow table is then lifted up 40mm and then dropped 15 times, causing the concrete to flow after this the diameter of flow of the concrete is measured.

3- Results

3-1 Results of Water Absorption Test

Results of water absorption test of concrete mixes at 28 days' age (one age) are described in Figure 2. Each result refers to the average of two specimens, all mixes improved the durability of concrete through the reduction of water absorption micro silica implemented in this work generally exhibits a reduction in the water absorption potential of concrete. In mixes with $CaCO_3$ less reduction in water absorption cab be recognized when comprised with micro silica mixes. Better enhancement was found in binary mixes due to the dual effect of micro silica and micro $CaCO_3$ by accelerate the hydration process and formation additional amount of C-S-H gel which develop the pore structure of concrete [3,5,10]. The same trend found for recycled silica gel and limestone also mixes with nanosilica and nano$CaCO_3$ showed reduction in water absorption the best result was with binary mixes too. This reduction resulted from the tiny particles of nanosilica place in pores in micron size and lead to porosity and permeability reduction, increasing the amount of nanosilica lessened slurry density, thus the permeability of slurries increased [11] so the water absorption increase beyond 3% nanosilica content. It is also revealed that the addition of CaCO3 nanoparticles not only led to much denser microstructure in concrete matrix but also changed the formation of hydration products, hence contributed to the improvement of early-age compressive strength and durability properties of concrete [5].

3-2 Results of Flow Slump Test

The effects of nano-CaCO3 and nano-SiO2 contents on slump flow of concrete mixtures are illustrated in Fig. 3. It can be seen that the slump flow gradually decreased with the increase of nano-CaCO3 and nano-SiO2 contents. Wengui Li founded that greater cement replacement amounts achieve lower flowability. this phenomenon is due to the fine particle size of nano materials which have much higher surface areas that absorb water leaving less free water to contribute to the flowability [6]. Erhan reported that the addition of nano silica to the mixture decrease the spread on flow table due to the increase of cohesion in the mortar [12]. The flowability for NC series was more favorable than that of NS series at the same content. This might be attributed to different particle size and reactivity for nano silica and nano $CaCO_3$, same results were proved by Zemei Wu how indicated that due to its surface effect, smaller particle sizes and higher surface energy, Ca2+ and OH- produced by cement hydration could be adsorbed in the surface of NC more easily, and the reduction of Ca2+ and OH- in cement paste solution leaded to speeding up the hydration reaction of cement [3].

Figure (4) and figure (5) showed the results for the mixes with micro additives and recycled additives respectively. In fig. (4) the decreasing in flow for micro silica mixes were greater than binary mixes and micro $CaCO_3$ mixes respectively, also mixes with recycled silica gel, crushed silica gel, limestone and binary mixes of crushed silica gel and limestone showed the same trend but the effect of crushed silica were greater than other due to reactivity of silica.

Table (1) Chemical analysis of the cement test*

Oxide	%
CaO	66.11
SiO_2	21.93
Al_2O_3	4.98
Fe_2O_3	3.10
MgO	2.0
K_2O	0.75
Na_2O	0.35
SO_3	2.25
Loss On Ignition (L.O.I)	2.39
Lime Saturation Factor	0.93
(L.S.F) Insoluble residue (I.R)	1.29
Free lime (F.L)	0.67
Compound Composition	%
C_3S	50
C_2S	20.48
C_3A	4.0
C_4AF	13.17

Table (2): Physical Properties of Cement test

Physical Properties	**Test Results**
Fineness , Blaine , cm^2/gm	3300
Setting Time :	
Initial hrs. ; min	2;05
Final hrs. ; min	4;00
Compressive Strength MPa	
3-days	20,0
7-days	25,0

Table (3) Sieve analysis and sulfate content of fine aggregate.

Sieve opening (mm)	**Accumulative passing, %**
10	100
4.75	94
2.36	85.6
1.18	76.9
0.60	46.3
0.3	10.8
0.15	1.1
0.075	0.5
Property	**Result**
SO_3, %	0.4

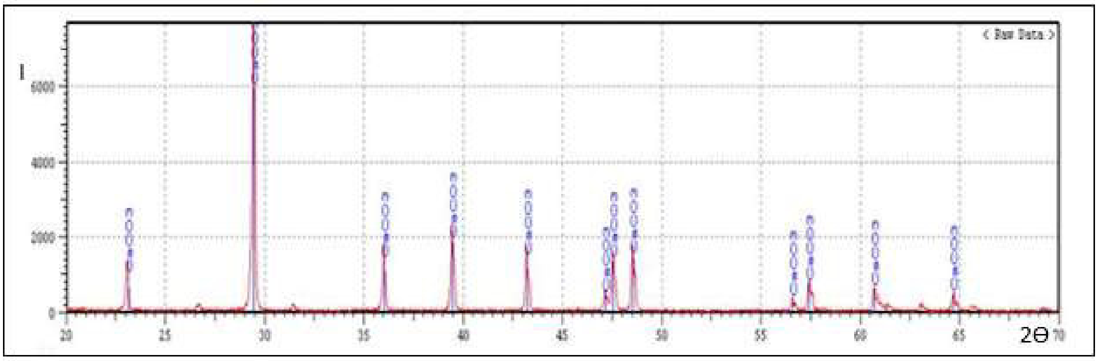
Table (4) Sieve analysis and sulfate content of gravel

Sieve opening (mm)	Accumulative passing, %
14	97
10	62
5	10
0.075	0.037
Property	**Result**
SO_3, %	0.09

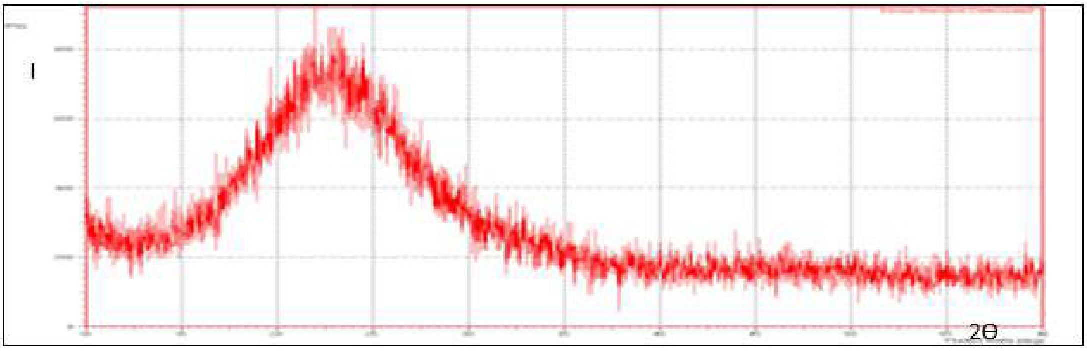
Table 5 : Mixes symbols, content and quantity

Mix symbol	Cement kg/m³	San dkg/m³	Gravel , kg/m³	w/b %	G54 kg/m³	MS kg/m³ (rep .%)	MC kg/m³ (rep .%)	L kg/m³ (re p.%)	SG kg/m³ (rep .%)	SGC kg/m³ (rep. %)	NS kg/m³ (rep .%)	NC kg/m³ (rep .%)
Control	515	721	1030	0.32	6.43	---	---	---	---	---	---	---
1MS	509.85	721	1030	0.32	6.43	5.15	---	---	---	---	---	---
2MS	504.7	721	1030	0.32	6.43	10.3						
3MS	499.55	721	1030	0.32	6.43	15.45						
4MS	494.4	721	1030	0.32	6.43	20.6						
1MC	509.85	721	1030	0.32	6.43		5.15					
2MC	504.7	721	1030	0.32	6.43		10.3					
3MC	499.55	721	1030	0.32	6.43		15.45					
4MC	494.4	721	1030	0.32	6.43		20.6					
1MS+MC	509.85	721	1030	0.32	6.43	2.575	2.575					
2MS+MC	504.7	721	1030	0.32	6.43	5.15	5.15					
3MS+MC	499.55	721	1030	0.32	6.43	7.725	7.725					
4MS+MC	494.4	721	1030	0.32	6.43	10.3	10.3					
1L	509.85	721	1030	0.32	6.43			5.15				
2L	504.7	721	1030	0.32	6.43			10.3				
3L	499.55	721	1030	0.32	6.43			15.45				
4L	494.4	721	1030	0.32	6.43			20.6				
1SG	509.85	721	1030	0.32	6.43				5.15			
2SG	504.7	721	1030	0.32	6.43				10.3			
3SG	499.55	721	1030	0.32	6.43				15.45			
4SG	494.4	721	1030	0.32	6.43				20.6			
1SGC	509.85	721	1030	0.32	6.43					5.15		
2SGC	504.7	721	1030	0.32	6.43					10.3		
3SGC	499.55	721	1030	0.32	6.43					15.45		
4SGC	494.4	721	1030	0.32	6.43					20.6		
1L+SGC	509.85	721	1030	0.32	6.43			**2.575**		2.575		
2L+SGC	504.7	721	1030	0.32	6.43			**5.15**		5.15		

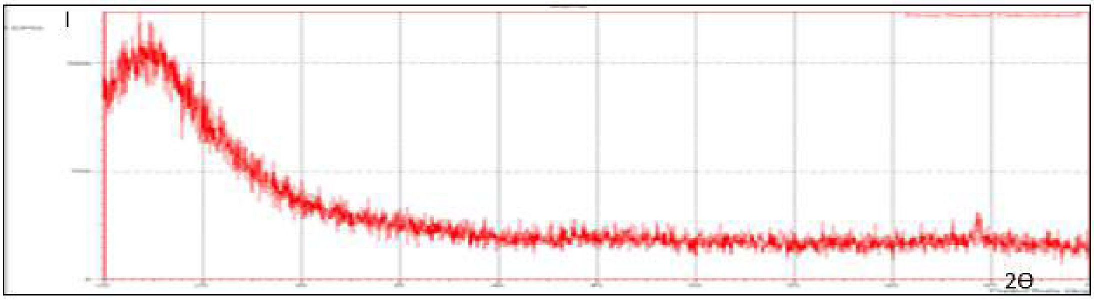
3L+SGC	499.55	721	1030	0.32	6.43			**7.725**		7.725		
4L+SGC	494.4	721	1030	0.32	6.43			**10.3**		10.3		
1NS	509.85	721	1030	0.32	6.43						5.15	
2NS	504.7	721	1030	0.32	6.43						10.3	
3NS	499.55	721	1030	0.32	6.43						15.45	
4NS	494.4	721	1030	0.32	6.43						20.6	
1NC	509.85	721	1030	0.32	6.43							5.15
2NC	504.7	721	1030	0.32	6.43							10.3
3NC	499.55	721	1030	0.32	6.43							15.45
4NC	494.4	721	1030	0.32	6.43							20.6
1NS+NC	509.85	721	1030	0.32	6.43						**2.575**	**2.575**
2NS+NC	504.7	721	1030	0.32	6.43						**5.15**	**5.15**
3NS+NC	499.55	721	1030	0.32	6.43						**7.725**	**7.725**
4NS+NC	494.4	721	1030	0.32	6.43						**10.3**	**10.3**



(a)



(b)



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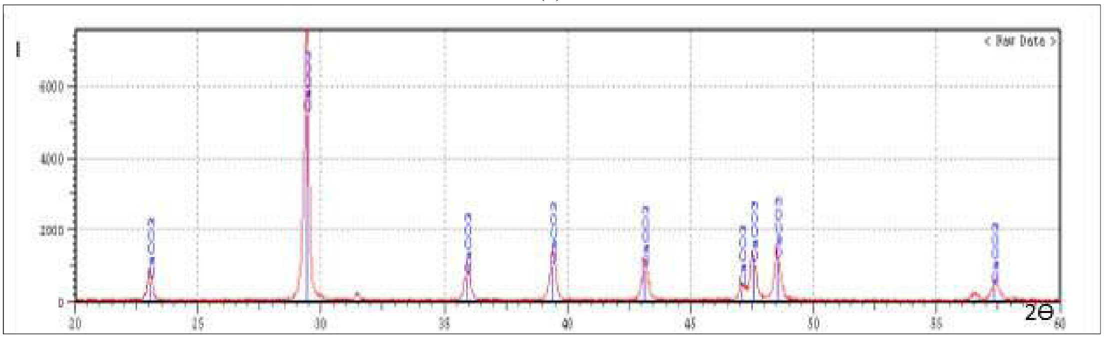

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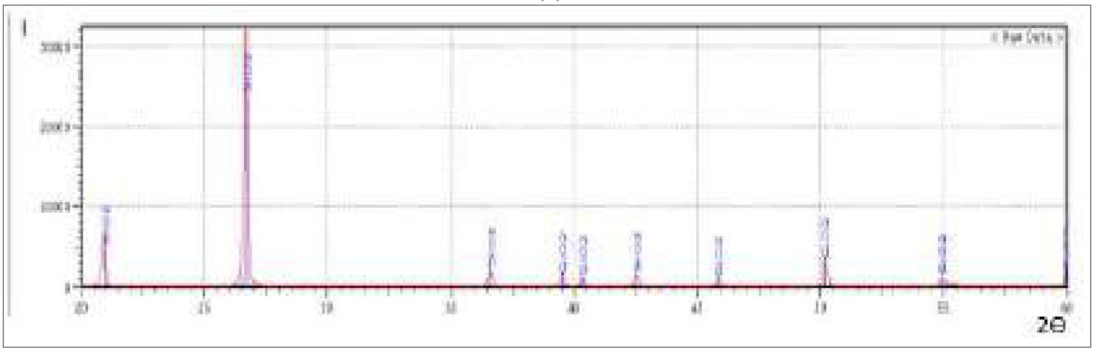
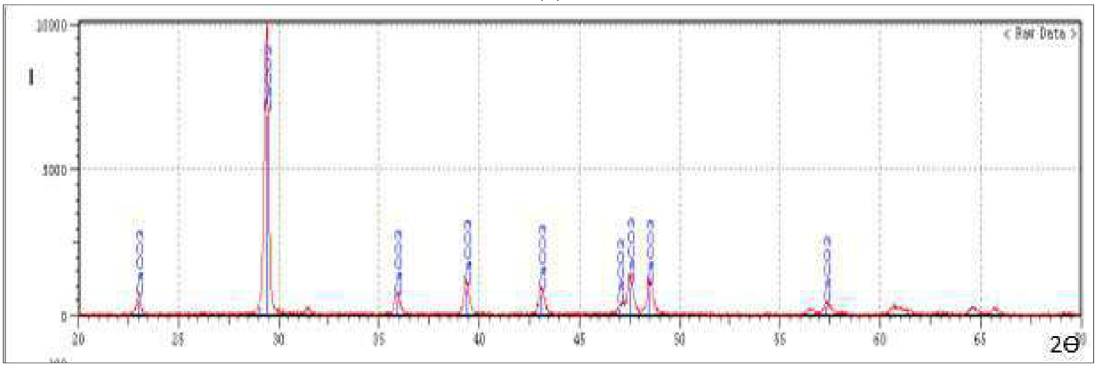
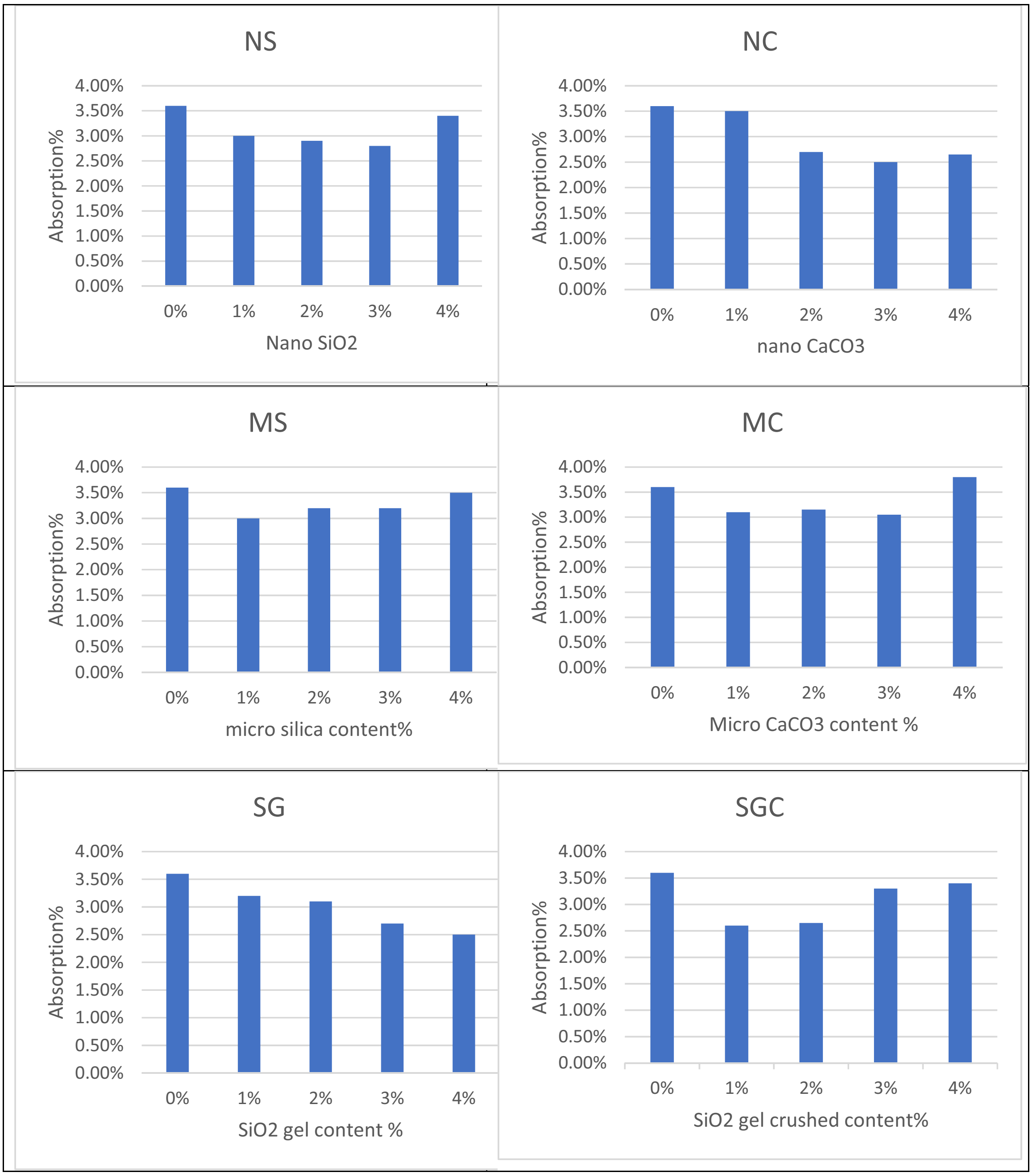


(e)



(f)

Figure (1) (a) XRD spectra of limestone powder. (b) XRD spectra of crushed silica gel powder
(c)XRD spectra of nano silica powder. (d) XRD spectra of nano $CaCO_3$
(e)XRD spectra of micro silica powder. (f) XRD spectra of micro $CaCO_3$


NS
Absorption%
4.00%
3.50%
3.00%
2.50%
2.00%
1.50%
1.00%
0.50%
0.00%
0%
1%
2%
3%
4%
Nano SiO2
NC
Absorption%
nano CaCO3
MS
Absorption%
micro silica content%
MC
Absorption%
Micro CaCO3 content %
SG
Absorption%
SiO2 gel content %
SGC
Absorption%
SiO2 gel crushed content%

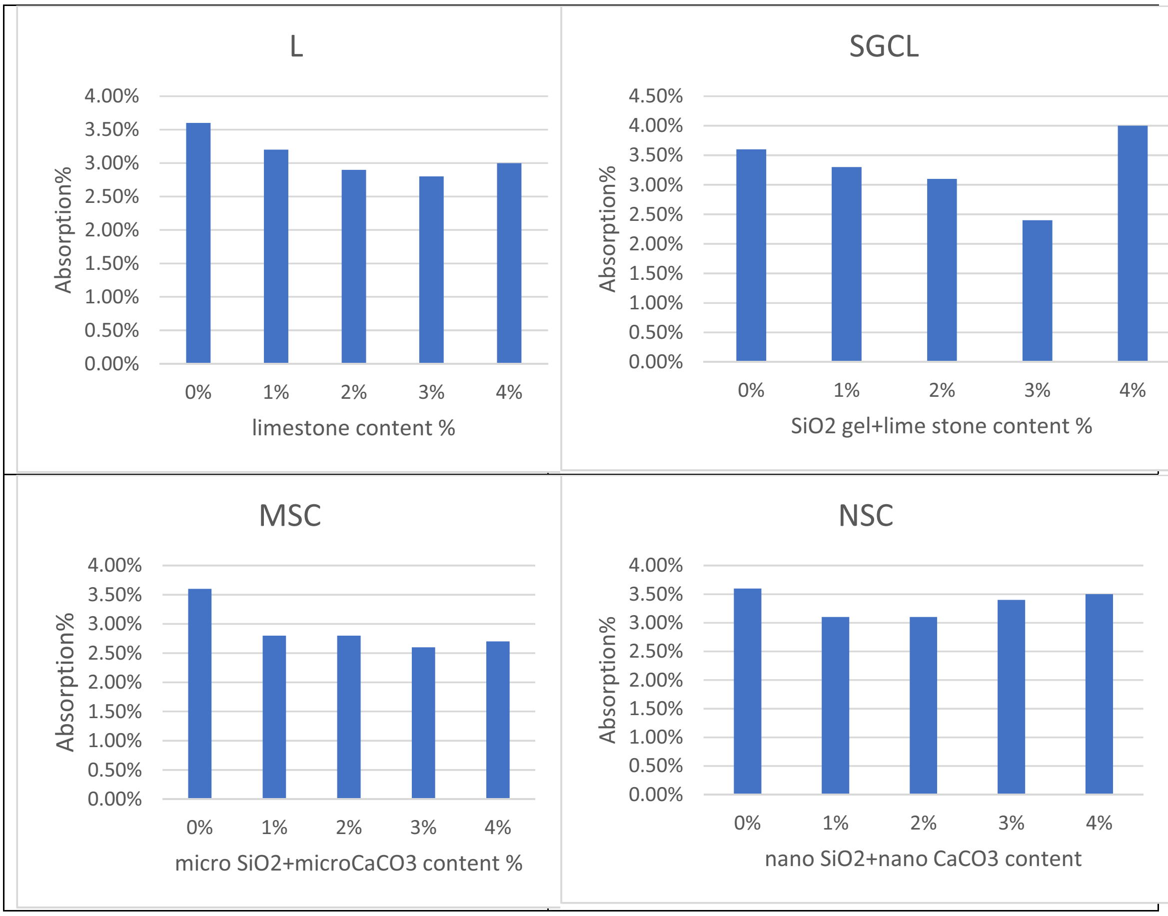


Figure (2) Results of water absorption test for all mixes

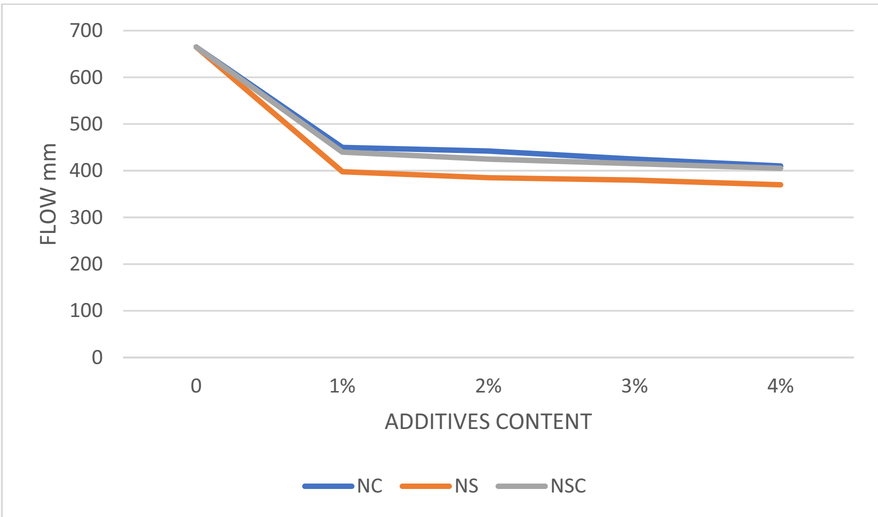


Figure (3) slump flow for concrete mixes with nano additives

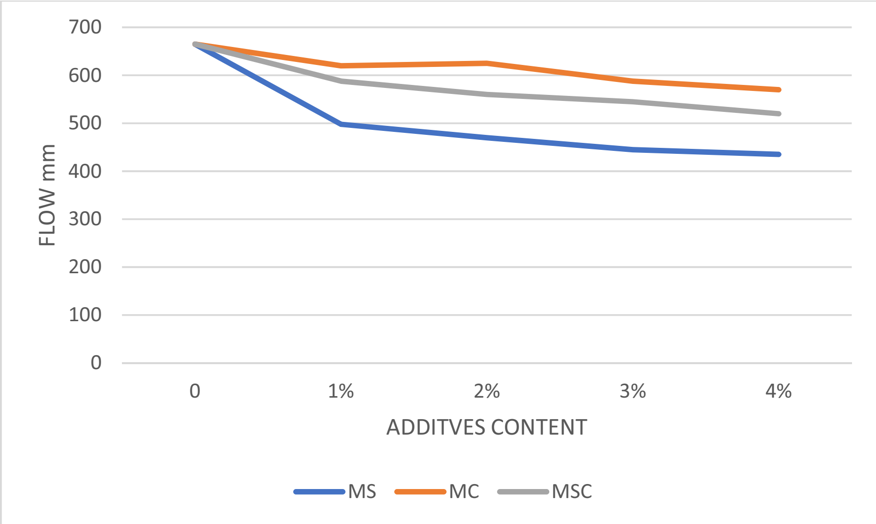


Figure (4) slump flow for concrete mixes with micro additives

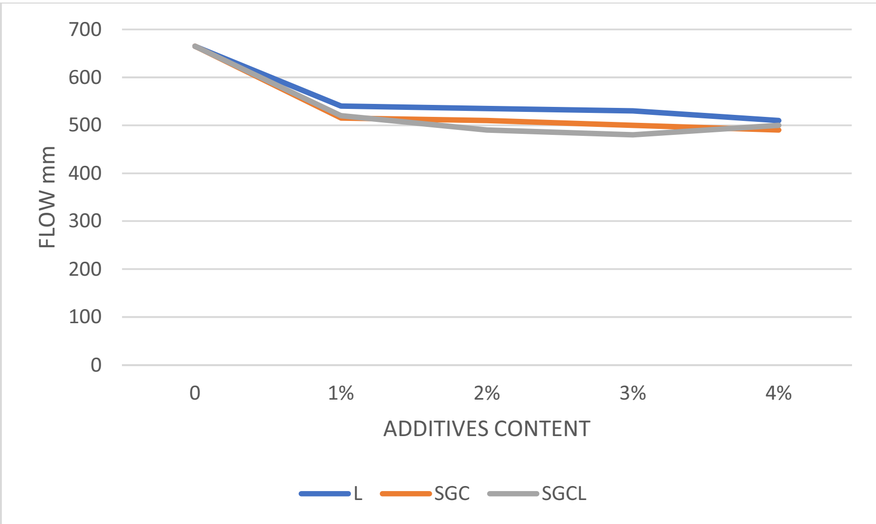


Figure (5) slump flow for concrete mixes with recycled additives

4- Conclusion

1- According to the experiments, the addition of nano-CaCO3 and nano-SiO2 could activate the cement hydration. With the increase of Nano particles, the flowability decreased while the water absorption resistance increased. Same trend recognized for micro and recycled replacements.

2- Binary mixes (nanoCaCO3 + nanoSiO2), (microCaCO3 + microSiO2) and (limestone+ silicagel) showed moderate effect compared with other mixes.

3- For both flowability and water absorption values were more effected by (nanoSiO2, microSiO2 and crushed silica gel) than (nanoCaCO3, microCaCO3 and limestone).

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