BEHAVIOUR OF NANO SILICA IN CEMENT MORTAR UNDER TENSION AND SHEAR

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Abstract : *This paper presents the split tension and shear strength properties of cement mortar prepared with nanosilica. The nanosilica is provided to the cement mortar as replacement to cement. The replacement was provided in the proportion of 0 to 14% and with an increment of 2%. The 28 and 90 days cube compressive strengths are evaluated and from the results the 10% NS mix is identified as effective replacement mix. Later for effective replacement of 10% NS, the split tension and shear strengths are found. From the results it is noticed that a remarkable strengths are noticed for effective mix.*

Index Terms - Nanosilica, Compressive strength, Effective mix, Split tension, Shear strength.

I. INTRODUCTION

The construction industry is looking new cementitious materials to enhance the strength and durability properties for cement mortar and concrete. In the journey of evaluation of new materials the composite materials with multi-scale internal structures are occupied the important place. More specifically, the cement paste matrix is basically a porous material composed of calcium hydroxide (portlandite), aluminates and unhydrated cement (clinker) embedded into an amorphous nanostructured hydration product, the so-called C–S–H (calcium silicate hydrate) gel (Gaitero, Campillo, & Guerrero, 2008). This gel is the dominant hydration product of the cement paste, not only because it is the most abundant component (50–70% by volume), but also because of its exceptionally good mechanical properties. Nanoparticles have a high surface-area-to volume ratio. In this way, nanoparticles have more than 50% of its atoms at the surface and are thus very reactive (Wiesner & Bottero (2007)). The behaviour of such materials is mainly influenced by chemical reactions at the interface, and by the fact that they easily form agglomerates. When higher surface area is to be wetted, it decreases free dispersant water in aqueous systems available in the mixture. Therefore, the use of nanoparticles in mortars and concretes significantly modify their behavior not only in the fresh, but also in the hardened conditions, as well as the physical/mechanical and microstructure development (Senff et al. (2009)). In recent years, the use of nanoparticles has received particular attention in many fields of applications to fabricate materials with new functionalities. When ultrafine particles are incorporated into Portland cement paste, mortar or concrete, materials with different characteristics from conventional materials were obtained (Lea (1998), Li et al. (2004), Neville (1996)). The performance of these cementitious-based materials is strongly dependent on nano-sized solid particles, such as particles of calcium–silicate–hydrates (C–S–H), or nano-sized porosity at the interfacial transition zone between cement and aggregate particles. Typical properties affected by nano-sized particles or voids are strength, durability, shrinkage and steel-bond (Collepardi et al., (2005)). Nanoparticles of SiO_2 (nano-silica) can fill the spaces between particles of gel of C–S–H, acting as a nano-filler. Furthermore, by the pozzolanic reaction with calcium hydroxide, the amount of C–S–H increases, resulting in higher densification of the matrix, thus improving the strength and durability of the material (Choolaei et al. (2012), Hou et al.(2013), Zapata et al.(2013)). Previous researches (Björnström et al. (2004), Lea (1998), Qing et al. (2007)) indicate that the inclusion of nanoparticles modifies fresh and hardened state properties, even when compared with conventional mineral additions. Colloidal particles of amorphous silica appear to considerably impact the process of C_3S hydration (Björnström et al. 2004). Nano-silica decreased the setting time of mortar when compared with silica fume (SF) (Qing et al.(2007)) and reduced bleeding water and segregation, while improved the cohesiveness of the mixtures in the fresh state (Collepardi et al. (2002),). Nano-silica-added cement paste showed reduction in setting time (Lin et al.(2008), Singh et al.(2011),Singh et al. (2012)) shortened duration of dormant and induction period of hydration, shortening of time to reach peak heat of hydration and increased production of calcium hydroxide at early ages (Ltifi et al. (2011), Senff et al., (2009)). When combined with ultrafine fly ash, better performance is assured than that achieved by use of SF (Lea (1998), Li et al. (2004)). Besides, the compressive strength of mortar or concrete with SF was improved when compared with formulations without addition (Jo et al(2007), Li et al.(2004), Li et al (2006)). Nano-silica addition increased the quantity of C–S–H and C–A–H in the paste (Tobón et al. (2012)). Addition of nano-silica into cement paste and mortar demand more water to retain its workability (Quercia et al. (2012)). To avoid adverse effects on workability, Berra et al. (2012) suggested delayed addition of water, stating that instead of adding all the mixing water at a time, certain amount of water should be added later on.

In particular, the developments in nano-science have had a great impact on concrete industry. Nano-materials have been used in concrete industry over the past decade. Few studies till date are reported with nanoparticles such as nano-silica (nano-SiO2) and nano-titanium oxide (nano-TiO2), nano-iron (nano-Fe2 O3), nano-alumina (nano-Al2 O3) (Li, 2004; Shekari & Razzaghi, 2011). Additionally, a limited number of investigations are dealing with the manufacture of nano-sized cement particles and the development of nano binders. Thus, limiting the review of literature work to use of nano-silica in cementitious compositions, research has shown that incorporation of nanoparticles in cement matrix could improve durability and mechanical properties of cement-based materials. Nano-silica (nS) in particular has found wide usage in this field because of its high reactivity and very large specific surface area, which results in a high degree of pozzolanic activity. Nano-silica further accelerates the dissolution of C3 S and formation of C–S–H with its activity being inversely proportional to the size, and also provides nucleation sites for C–S–H (Jo et al. (2007)). Even small additions (0.6 wt. % binder) of nS are very efficient and compare to much larger amounts of SF in terms of improvement in mechanical properties of cement-based materials. This is especially pronounced at early ages and for concretes with regular strength grade (Pourjavadi et al.(2012)). From the nano-indentation studies, it was observed that the nano-silica addition significantly alters the proportions of low stiffness and high stiffness C–S–H (Hou et al. (2013), Mondal et al. (2010)). Nano-material and cement composites in the construction industry, extensive research is going on to improve the performance of various building materials and development of durable and sustainable concrete. Among all the nano-materials, nano-silica is the most widely used material in the cement and concrete to improve the performance because of its pozzolanic reactivity besides the pore-filling effect. Paste and mortar with nano-silica various researchers have investigated the effect of nano-silica on pastes and mortars. Still more research works are to need to evaluate the strength properties for cement mortar with addition or replacement to cement. In the present study, it is planned to replace the cement by nano silica with maximum extent of 0 to 14% with an incremental replacement of 2%. In the past many work has been carried out up to 5%, hence here in it is provided with little more replacement ratio for the cement mortar in order to evaluate behavior of NS in the cement mortar mix. For the present study the following objective are taken in to consideration.

II. OBJECTIVES

(i) The cube compressive strength is to evaluate for various replacements so as to identify the effective mix.
(ii) For effective mix split tension and shear strengths are to evaluate.

III. EXPERIMENTAL PROGRAM AND METHOD OF CASTING

Total 24 cubes with 70.5x70.5x70.5mm are cast for eight mixes to evaluate the cube compressive strengths and the cubes are tested at 28th day. For effective mix, 6 cylinders with dimensions of 100x200mm are cast to find split tensile strength (figure 2). To know shear strength of cement mortar, 6 cylinders with dimension of 150x300mm are cast and during casting slots are created for cylinder with depth of 50mm, so that the specimen is to fail in shear (figure 3). These cylinders tested in the compression testing machine at 28 and 90^{th} day. For all the elements binder to cement is provided as 1:3 along with water binder ratio of 0.4. During the mixing of super plasticizer was used to the cement mortar, to make it more workable. For mixing of materials, cement mortar mixing machine is used to achieve uniform mixture. For experimental work the following materials are used.

IV. MATERIALS

4.1 Cement

Ordinary Portland cement (Grade 53) was used. The specific gravity of cement found as 3.12 and the initial and finial setting times are noticed as 30 and 615 minutes respectively.

4.2 Water

Portable water was used for mixing and curing of specimens.

4.3 Fine Aggregate

Ennore sand was used for the work and the sand was taken in three grades of fine, medium and coarse as specified in the Indian Standard Sand IS650:1991.

4.4 NanoSilica

The size particle is 40 nanometers and it is in powder form. The SiO_2 content is about 99.8% in the nano silica. The used nano silica can be viewed in the figure 4.1.

Figure 4.1.NanoSilica

4.6 Super Plasticizer:

Glenium 51 was used as super plasticizer and it is in the form of powder. This is added to the water and the same water is added to cement mortar mix.

V. TEST RESULTS

5.1 Compressive Strengths

The cube compressive strength results for 28 and 90 days are presented in Table 5.1 and Figure 4.1. From the results it is observed that, the mix with 10%NS showing maximum compressive strengths than the other replacements. At higher dosage of NS the mix may not utilize the NS effectively by the cement. In general the additive or replacement pozzoloanic materials for the cement may react with $CaOH_2$ and produces additional CSH gel to enhance the strengths. In the present study the NS effectively participate with calcium hydroxide in the cement mortar up to 10% and at later stages its presence may act as filler material, without out any major contribution towards strength. Hence from the results it is came to know that, the mix with 10%NS is effective, so for evaluation of split tensile and shear strengths this mix is consider and also the base mix without NS is considered for the purpose of comparison.

Table 5.1: Compressive Strength for OPC+NS in (MPa)

Sl.No	Mix of OPC+NS	28 days compressive strength (MPa)	90 days compressive strength (MPa)
1	100%+0%	62.95	64.75
2	98%+2%	67.51	68.78
3	96%+4%	74.50	76.47
4	94%+6%	81.61	83.84
5	92%+8%	82.78	84.98
6	90%+10%	**84.10**	**86.20**
7	88%+12%	81.25	81.85
8	86%+12%	76.56	77.15

5.2 Split tensile strength

The split tensile strengths for the 0% and 10%NS mixes are presented in Table 5.2 and testing of cylinder can be observed in figure 2. From the results is observed that, the strengths are increased with presence of NS and also with the elapsed of time from 28 to 90 days. The of increment of strength for 10%NS mix at 28 and 90 days is 21 and 34.67% respectively when compared with 28 days strength of reference mix (without nano silica). B.Kartikeyan et al. (2014) has observed the similar behavior of split tensile strength results for their experimental work done on ground silica fume. In their work also for 10% ground silica fume, the strength increment is observed as 19.2%. Rishav Garg et al. (2016) have conducted the split tensile strength for cement mortar and found that the split tensile strength is 4.02MPa for 3%NS at 28 days. But in the present work the split tensile strength is 3.91MPa, perhaps it may due to size of nano particle. They have used 20nm but in the present work the size of particle is 40nm, this may influence to affect strength results.

Table 5.2: Split Tensile Strength for OPC+NS

Mixture	Split Tensile strength (MPa)					
OPC+NS	Load in kN	28 Days Strength for OPC	28 Days Average Strength	Load in kN	90 Days Strength for OPC	90 Days Average Strength
100%+0%	103.2	3.29	3.23	109.5	3.49	3.43
	100.5	3.20		106.6	3.39	
	100.8	3.21		107.0	3.41	
90%+10%	124.8	3.97	3.91	138.9	4.42	4.35
	121.6	3.87		135.2	4.31	
	122.0	3.88		135.7	4.32	

Figure 5.1: Cylinder under split tensile test

5.3 Shear Strength

The shear strength results for 0 and 10%NS mixes are presented in Table 5.3. These results are pertaining to 28 and 90 days. From the results it is observed that, the strengths are increasing by increasing the age for the tested specimens and also with presence of NS for the mix. For NS mix the shear strength increased by 15.12 and 20.16% when compared with 28 days mix without NS. By observing the tested sample (figure 3) the failure was occurred by propagating the crack in the shear plane.

Table 5.3: Shear Strength for OPC+NS

Mixture	Shear strength (MPa)					
	28 days			90 days		
OPC+NS	Load (kN)	Shear strength	Average	Load (kN)	Shear strength	Average
100%+0%	9.0	1.21	1.19	9.5	1.26	1.24
	8.8	1.18		9.2	1.23	
	8.8	1.18		9.2	1.23	
90%+10%	10.5	1.39	1.37	10.9	1.45	1.43
	10.2	1.36		10.6	1.42	
	10.2	1.36		10.6	1.42	

Figure 5.2: Cylinder under shear test

CONCLUSIONS

From the present experimental work the following conclusions are arrived

i. The maximum compressive strength is attained for 10%NS mix and it is noticed as 84.10 and 86.20MPa for 28 and 90 days.
ii. The 10%NS mix is considered as effective mix than the others, because it exhibited higher compressive strength over other mixes.
iii. The compressive, split tensile and shear strengths are increasing as the days elapsed for the cast specimens.
iv. The split tensile strength is increased for the 10%NS mix when compared with reference mix and the strength increment is noticed as 21.00 and 34.67%.
v. The shear strength is increased for 10%NS mix when compared with reference mix and it observed as 15.12 and 20.16% for 28 and 90 days.

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