International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 5 Issue 04, April-2016

Split Tensile Strength of Cement Mortar Incorporating Micro and Nano Silica at Early Ages

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***Abstract*— This paper presents the split tensile strength of cement mortar incorporating micro-silica (MS), nano-silica (NS) and micro-silica with optimized content of nano-silica (MS+NS) as a partial replacement of cement. The split tensile strength of the mortar specimens were determined at 3, 7, and 28 days. The results were correlated by ANNOVA analysis and the results were correlated with the values of R^2 obtained by analysis. The results reveal the enhanced strength and improved value of correlation coefficient R^2 of mortar specimens with proper combination of micro and nano silica resulting in better performance as compared to conventional specimens.**

Keywords*— *Split tensile strength; strength; ANNOVA; nano-silica; micro-silica

I. Introduction

The split tensile strength of cement mortars is significantly affected by the mix proportion , chemical composition and the water, binder ratio [1]. The consumption of cement leads to higher value of carbon footprints globally. In this regard, supplementary cementitious materials (SCMs) as a partial replacement of cement have been extensively studied by researches in recent years including nano-Fe_2O_3 [3], nano-TiO_2[4]. The pozzolanic materials such as micro-silica (MS) and nano-silica (NS) are gaining significant attention due to their better performance as compared to other additives [2, 6].These materials improve the mechanical strength of the cementitious materials by improving their pore size distribution and chemical nature in the fresh stage leading to enhanced life. Mortar is the paste prepared by the addition of fixed amount of water in the matrix containing binding material such as cement or any other material having binding properties like microsilica & nano silica and fine aggregate. The quality, strength & durability of the mortar depend mainly on the quality & quantity of the matrix. The incorporating effect of MS and NS is tri-fold due to pozzolanic action and filler effect. The silica particles of NS and MS react with the calcium hydroxide which is produced by hydration of cement resulting in the formation of CSH gel that further strengthen the cement matrix. Due to high surface area, the fine particles of MS and NS act as filler resulting in crystallization of CSH gel between the voids to enhance the split tensile strength. Many chemical, electrochemical & physical processes are responsible to cause cracking in cement mortar & hence affecting its strength. It is difficult to classify the exact cause of deterioration of cement mortar because of interacting and reinforcing nature of various chemical & electrochemical factors. The properties of the cement mortar keep on changing with time due to chemical interactions of the matrix with aggressive environment and the microstructure of the mix. The solid phase in well hydrated cement mortar is primarily composed of hydrates of calcium like C-S-H, C-A-SH or CH and is relatively insoluble with high pH value. Due to addition of SCM's, the hydration of cement gets accelerated and the availability of calcium hydroxide increases for further reaction with silica particles leading to consumption of calcium hydroxide. As a result, the microstructure of the cement matrix gets more dense and homogeneous with enhanced strength. NS has comparatively finer particle size and greater specific surface than MS and exhibit greater nucleation, pozzolanic and filler effect but form agglеromerates at higher content that limits its use as SCM [5, 7]. This paper presents the split tensile strength correlation of conventional mortar specimens with incorporation of MS, NS and MS in presence of optimized content of NS (MS+NS) in mortar specimens. The study is based on the split tensile strength measurements at 3, 7, and 28 days and the determination of the optimum content of NS for partial replacement of cement. The results have been critically analyzed in terms of pozzolanic action of MS and NS. ANNOVA analysis of mortar specimen has been carried out to support the results. The study reveals the better performance of NS in presence of MS at an optimized content.

II. MATERIALS AND METHODS

A.Materials:

Ordinary Portland Cement (OPC) 43 grade with standard consistency of 29.0% complying with Indian Standard IS: 8112-2013 was used for preparation of all the specimens. The cement particles had the fineness equal to 310 m^2/kg and specific gravity equal to 3.15. Standard Ennore sand was used after standard sieve analysis was performed in compliance with IS: 2386 (Part-I)-1963. Micro-silica (MS) with bulk density 630 kg/m^3 and colloidal nano-silica (NS) with solid strength 30% was used as such without any modification. The physical characteristics of the materials used has been provided in table 1. The water used to prepare all specimens was in accordance to IS: 456-2000.

TABLE 1. PHYSICAL CHARACTERISTICS OF THE MATERIALS

Properties	Specific Gravity	Average particle size	Specific Surface (m^2/ g)
OPC	3.15	16 μm	0.31
NS	1.31	20 nm	140
MS	2.21	<1 μm	13-30

B. Methodology for Mix Proportion and testing of the specimens:

All the specimens were prepared by mechanical mixing in accordance with IS: 2250-1981. The Control mix (CMS) with water/binder ratio (W/B) of 0.45 was prepared without replacement of cement with MS and NS. The mortar paste was prepared by using water/binder ratio (W/B) of 0.45 and cement/standard sand weight ratio (C/S) of 1:3 for all the specimens. Cement was replaced by MS with content varying from 5% to 20 % @ 5% (Specimens MM1 to MM4) and NS with content varying from 0.5 % to 1.25% @ 0.25% (Specimens MN1 to MN4). The specimen incorporating NS with maximum split tensile strength at 28 days was selected for optimum content and a combination of MS with content varying from 5% to 20 % @ 5% at fixed optimum NS (1%) was used to replace cement (Specimens MNM1 to MNM4). The quantity of water was kept constant so as not to affect the flowability adversely. Colloidal NS contains specific amount of water, hence, the amount of water was reduced accordingly to prepare the specimens.

The mix proportion of the specimens has been shown in table 2.

TABLE 2. MIX PROPORTION OF THE SPECIMENS

Specimen	Water (g)	Cement (g)	Sand (g)	W/B	MS (g)	NS (g)
CMS	90.000	200.0	600	0.45	-	-
MM1	90.000	190.0	600	0.45	10	-
MM2	90.000	180.0	600	0.45	20	-
MM3	90.000	170.0	600	0.45	30	-
MM4	90.000	160.0	600	0.45	40	-
MN1	87.670	199.0	600	0.45	-	1.0
MN2	86.500	198.5	600	0.45	-	1.5
MN3	85.340	198.0	600	0.45	-	2.0
MN4	84.175	197.5	600	0.45	-	2.5
MNM1	85.340	188.0	600	0.45	10	2.0
MNM2	85.340	178.0	600	0.45	20	2.0
MNM3	85.340	168.0	600	0.45	30	2.0
MNM4	85.340	158.0	600	0.45	40	2.0

For each mix, nine cylindrical specimens of 100 mm x 200 mm were prepared. The specimens were demoulded after 24 hours and cured in water at $27 \pm 2°C$ for 3, 7, and 28 days. The split tensile strength of the specimens, f_{ct} was determined in accordance with the IS 5816-1999 by using the equation:

$$f_{ct} = \frac{2P}{\pi dl} \quad \text{---(1)}$$

Where, P is the load applied to the specimen, d is the diameter (100 mm) and l is the length of the specimen (200 mm).

III. RESULTS AND DISCUSSION

A. Split tensile strength:

The pozzolanic behavior of MS and NS strongly influences the split tensile strength of the mortar specimens due to their reaction with the CH produced during hydration of cement [8]. This reaction further results in the promotion of hydration reaction and generation of dense C-S-H gel resulting in increased split tensile strength of mortar specimens [9,10]. The split tensile strengths of CMS and mortar specimens incorporating MS, NS and MS+NS had been determined at a curing age of 3, 7 and 28, days. The split tensile strength of mortar specimens was found to increase gradually on incorporation with MS and NS indicating the densification of the cement matrix due to the formation of C-S-H gel (Table 3).

In case of the specimens incorporating MS, an increase of 4%, 7%, 10% and 9% was observed at 3 days, 4%, 8%, 11% and 11% at 7 days and 7%, 10%, 12% and 11% increase in split tensile strength was observed at 28 days. The specimens incorporated with NS showed an increase in split tensile strength of 13.0%, 16%, 21% and 17% at 3 days, 23%, 25%, 26% and 24% at 7 days and 22%, 21%, 23% and 21% at 28 days. The combination of MS at optimized content of NS showed a remarkable increase in split tensile strength as the increase was 23%, 26%, 27% and 24% at 3 days, 26%, 30%, 31% and 29% at 7 days and 26%, 27%, 26% and 26% at 28 days.

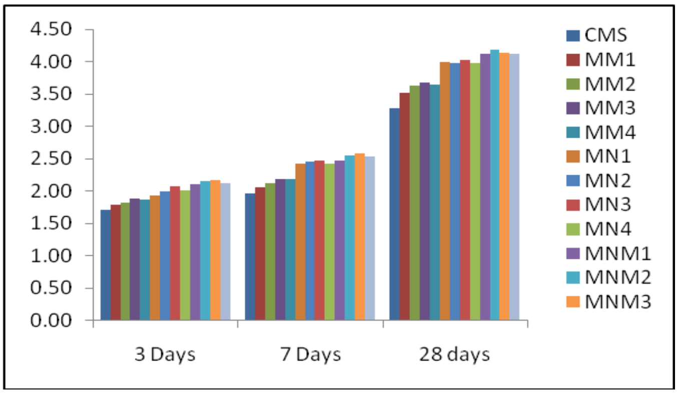

Fig 1. Effect of curing age on split tensile strength of Specimens

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
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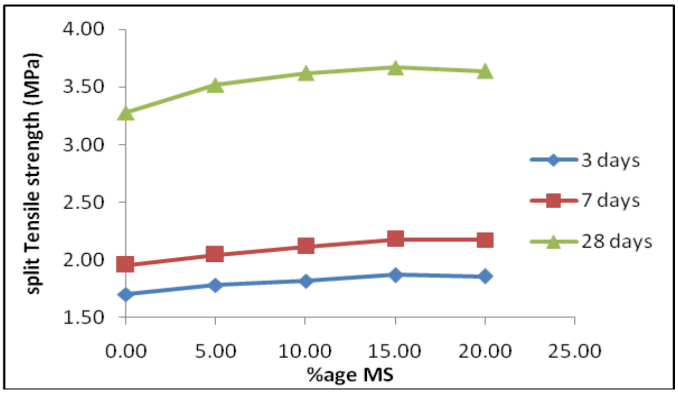

Fig 2. Effect of %MS on split tensile strength of Specimens

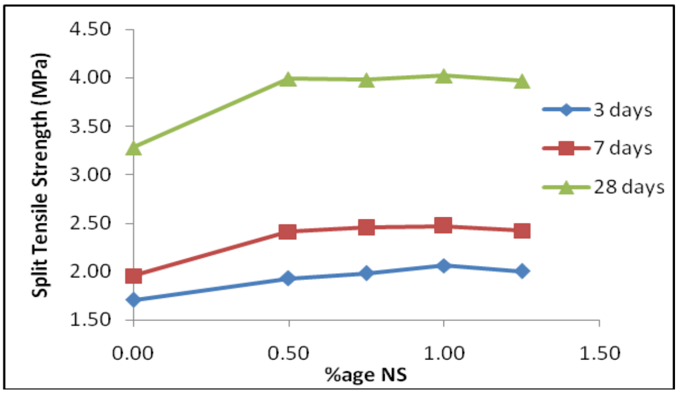

Fig 3. Effect of %NS on split tensile strength of Specimens

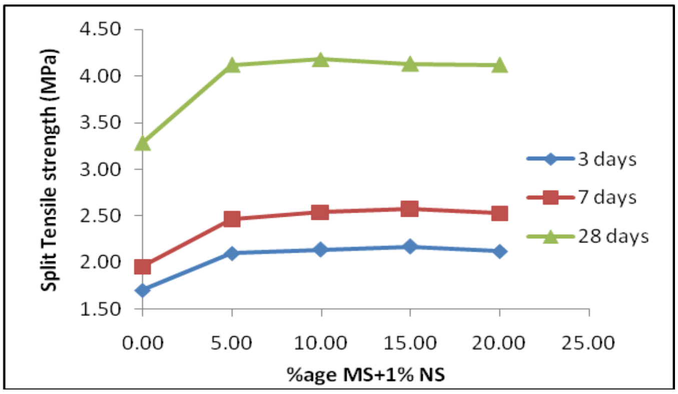

Fig 4. Effect of %MS+NS on split tensile strength of Specimens

Further, it was found that the mortar specimen incorporated with 1% NS developed maximum increase in the split tensile strength, hence 1% NS was selected as the optimum percentage for incorporation of specimens with MS+NS. These specimens resulted in further increase in split tensile strength as compared to earlier specimens due to better distribution of the particles and enhanced filler effect leading to increase of the split tensile strength. However, all the specimens showed an increase of the split tensile strength only up to a particular percentage of the incorporated NS/MS and MS+NS particles and decreased afterwards. This observation can be attributed to the agglomeration tendency and increased friction of NS and MS particles with increase in their incorporation percentage. As a result, the pozzolanic particles

TABLE 3. SPLIT TENSILE STRENGTH OF THE SPECIMENS

Specimens	Split tensile strength		
	3 days	*7 days*	*28 days*
CMS	1.70	1.96	3.28
MM1	1.78	2.04	3.52
MM2	1.82	2.12	3.62
MM3	1.87	2.18	3.67
MM4	1.86	2.18	3.64
MN1	1.93	2.41	3.99
MN2	1.98	2.45	3.98
MN3	2.06	2.47	4.02
MN4	2.00	2.42	3.97
MNM1	2.10	2.46	4.12
MNM2	2.14	2.54	4.18
MNM3	2.17	2.57	4.13
MNM4	2.12	2.53	4.12

may not show their pozzolanic behavior leading to a decrease in densification of the matrix and split tensile strength.

B.ANNOVA analysis:

The regression model analysis was carried out for the specimens to estimate R^2, the correlation coefficient of the polynomial regression fitting of second order. The content percentage of MS, NS and MS+1%NS at the curing age of 3, 7and 28 days were correlated for split tensile strength of specimens in non-linear second order model equations to represent the maximized objective function (Y) as in Eq. (2).

$$Y = a_o + a_1 x_1 + a_2 x_2 + a_{11} x_1^2 + a_{22} x_2^2 + a_{12} x_1 x_2 \text{-----} \quad (2)$$

Where x_1 is the content dosage of MS, x_2 is the content dosage of NS, $a_0, a_1, a_2, a_{11}, a_{22}$ and a_{12} are the model coefficients.

TABLE 4. MULTIPLE REGRESSION ANALYSIS RESULTS FOR SPLIT TENSILE STRENGTH

Additive	Curing age (Days)	Regression coefficient			Correlation coeff. (R^2)
		a_o	a_1	a_2	
MS	3	1.699	0.007	0.0	0.898
	7	1.935	0.032	0.001	0.802
	28	3.276	0.035	0.001	0.997
NS	3	1.706	1.227	0.665	0.995
	7	1.969	2.280	1.200	0.991
	28	3.308	2.978	1.578	0.979
MS+1.0%NS	3	1.710	0.077	0.002	0.952
	7	2.037	0.154	0.006	0.898
	28	3.353	0.118	0.004	0.869

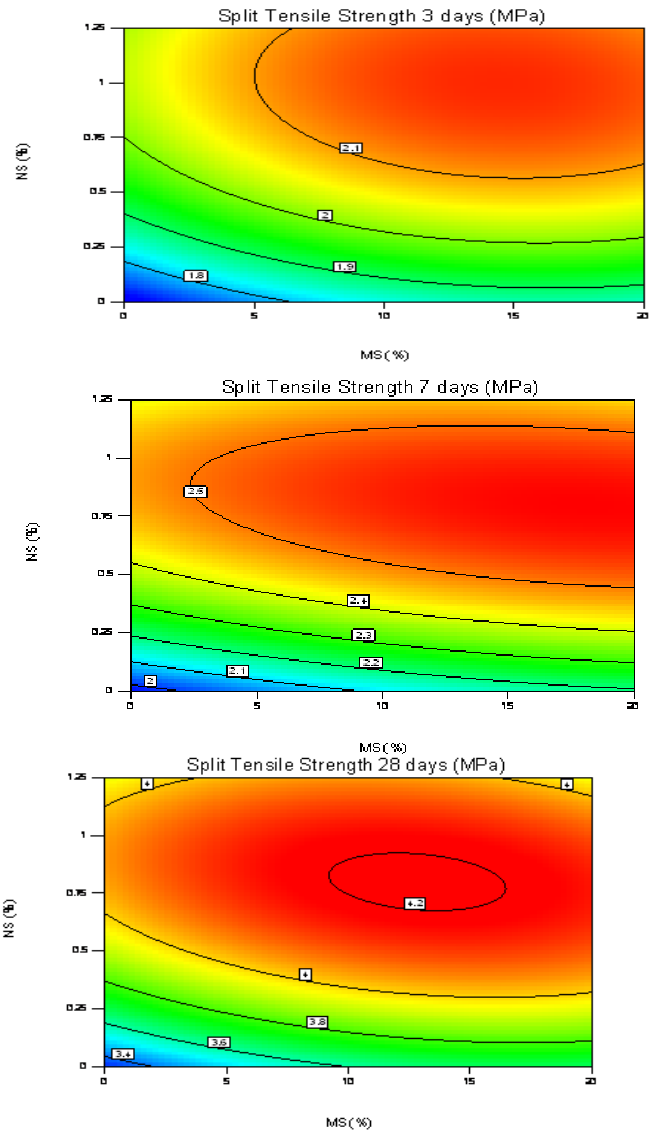

Fig 5. Iso response curve of ANNOVA

The estimated values of R^2 from polynomial regression analysis results has been given in table 4. The higher value of R^2 confirms the validity of the results.

IV. CONCLUSION

The study was aimed to study the effect of replacement of cement in cement mortar with micro silica, nano silica and combination of both. MS content was varied as 5%, 10%, 15% and 20% and NS as 0.5%, 0.75%, 1.0% & 1.25% by weight replacement of cement to investigate the effects on the split tensile strength at 3days, 7 days & 28 days of curing ages on cement mortar. On the basis of this study, the following conclusions can be stated:

1. The split tensile strength of all the specimens containing MS was higher as compared to the mortar mixture without MS because of the enhanced microstructure and improvement in aggregate-paste bond which is due to the conversion of the CH (calcium hydroxide) to CSH (calcium silicate hydrate) in the presence of reactive silica.
2. The Split tensile strength strength all the specimens containing NS was higher in comparison to control mix and the specimens having MS due to reduction in micro cracks of mortars due to higher surface area of NS and thereby increasing compactness.
3. There was sharp increase in Split tensile strength by adding optimum amount of NS & varying percentage of MS.
4. The split tensile strength of concrete mix increases with age.
5. The split tensile strength increases with addition of MS upto 15% and the decreases and it increases with addition of NS upto 1.0% and then decreases.
6. The split tensile strength was found to increase for all mixes with additives at all days in comparison to control mix without any additive attributed to the fact that adding MS improves dispersion of the NS in the mortar specimens and thereby increasing the split tensile strength.
7. The results were well correlated with the improvement in the R^2 value in ANNOVA.

ACKNOWLEDGEMENTS

The authors are grateful to acknowledge all the support extended by I.K Gujral Punjab Technical University, Kapurthala during the tenure of this study.

REFERENCES

[1] Rao GA. Investigations on the performance of silica fume-incorporated cement pastes and mortars. Cem Concr Res 2003; 33: 1765–70.

[2] Senff L, Hotza D, Repette WL, Ferreira VM, Labrincha J a. Mortars with nano-SiO2 and micro-SiO2 investigated by experimental design. Constr Build Mater. 2010;24(8):1432-1437. doi:10.1016/j.conbuildmat.2010.01.012.

[3] Li H, Xiao HG, Yuan J, Ou J. Microstructure of cement mortar with nano-particles. Compos Part B Eng 2004; 35: 185–9.

[4] Feng D, Xie N, Gong C, Leng Z, Xiao H, Li H. Portland Cement Paste Modified by TiO2 Nanoparticles: A Microstructure Perspective 2013.Ind. Eng. Chem. Res. 2013;52:11575-82.

[5] Hosseinpourpia R, Varshoee A, Soltani M, Hosseini P, Ziaei Tabari H. Production of waste bio-fiber cement-based composites reinforced with nano-SiO2 particles as a substitute for asbestos cement composites. Constr Build Mater 2012; 31: 105–11.

[6] Heikal M, Ali AI, Ismail MN, Ibrahim SANS. Behavior of composite cement pastes containing silica nano-particles at elevated temperature. Constr Build Mater 2014; 70: 339–50.

[7] Kong D, Du X, Wei S, Zhang H, Yang Y, Shah SP. Influence of nano-silica agglomeration on microstructure and properties of the hardened cement-based materials. Constr Build Mater. 2012;37:707-715. doi:10.1016/j.conbuildmat.2012.08.006.

[8] Ylmén R, Jäglid U, Steenari BM, Panas I. Early hydration and setting of Portland cement monitored by IR, SEM and Vicat techniques. Cem Concr Res 2009; 39: 433–9.

[9] Oltulu M, Şahin R. Single and combined effects of nano-SiO2, nano-Al2O3 and nano-Fe2O3 powders on split tensile strength and capillary permeability of cement mortar containing silica fume. Mater Sci Eng A 2011; 528: 7012–9.

[10] Stefanidou M, Papayianni I. Influence of nano-SiO2 on the Portland cement pastes. Compos Part B Eng 2012; 43: 2706–10.