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Effect of Colloidal Nanosilica on High Strength Rice Husk Ash Concrete

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ABSTRACT

Nowadays, supplementary cementitious materials (SCMs) are used in concrete because it reduces CO_2 emission during. The husks, which are production of cement, reduces cement contents, improve workability, increase strength and enhance durability. Pozzolanic reaction takes place when siliceous or aluminous material comes in contact with calcium hydroxide in the presence of moisture to form compounds possessing cementitious properties approximately 50 percent cellulose, 30 percent lignin and 20 percent silica, are incinerated by controlled combustion leaving behind an ash that predominantly consists of amorphous silica. Rice husk ash is highly pozzolanic due to its extremely high surface area (50,000 to 100,000 m^2/kg). The colloidal nano silica (CNS) which is nano material and behaved not only as a filler to improve cement micro-structure (porosity decrease), but also as a promoter of pozzolanic reaction used in cement for accelerating pozzolanic action due to which the cement sets faster than conventional mix. In the present study, the mineral admixture, rice husk ash (RHA) was used as 5, 10, 15% replacement for OPC in M60 grade of concrete. The 10% RHA was taken as optimum dose on the basis of workability and compressive strength. To this 10% RHA concrete, effect of 1, 2, 4, and 6% CNS addition were experimentally studied with various properties like workability, compressive strength and split tensile strength.

Keywords: colloidal nano silica, compressive strength, ordinary Portland cement, rice husk ash, split tensile strength

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INTRODUCTION AND LITERATURE REVIEW

Nanotechnology has attracted considerable scientific interest due to the new potential uses of particles in 1–100 nm scale [1]. At the nanoscale, physical, chemical, and biological properties vary from the properties of individual atoms and molecules of bulk matter. Therefore, it provides opportunity to develop new classes of advanced materials which meet the demands from high-tech applications [2]. Thus, industries may be able to re-engineer many existing products that function at unprecedented levels. A quickly growing range of applications of nonmaterial's in many fields has been observed in recent years [2]. Among them, nanosilica is a widely used nanomaterial with applications in polymer, adhesives, fiber optic strands, sealants, inks, paints, coatings, cosmetics, food additive and in cement-based building materials [3].

Concrete is a highly heterogeneous material produced by mixture of finely powdered cement, aggregates of various sizes and water with inherent physical, chemical and mechanical properties. A reaction between the cement and water yields calcium silicate hydrate, which stretches concrete strength and other mechanical properties of concrete, as well as some by-products are formed, including calcium hydroxide (CH), gel pores etc. With the addition of suitable cementitious materials, mostly siliceous or aluminous with cement which will react with excess calcium hydroxide and produce additional C-S-H with the replacement of porous CH and refines the pore structure and reduces permeability of gases and water in concrete [4].

Mehta (1978) [5] obtained a patent for the production of Rice Husk Ash (RHA), which could be used as pozzolan. Since then, a few studies have been carried out on the production of RHA. The sensitivity of incinerating conditions is the primary reason that prevents the widespread use of this material as pozzolan.

A comprehensive study conducted by the authors reveals that, incineration condition of 500°C and 120 min is found to be the optimum combination for the production of ash with maximum density, maximum fineness, maximum amorphous silica content, maximum pozzolanicity and the least production energy [6].

Rao et al (2014) [7] stated that, for every 1000 kg of paddy milled, about 220 kg (22%) of husk is produced, and when this husk is burnt in the boilers, about 55kg (25%) of RHA is generated.

Akeke et al (2012) [8], investigated the effects of introducing rice husk ash as a partial replacement of OPC on the structural properties of concrete. They found compressive strength ranging from 33-38.4N/mm^2 at replacement percentages of 10–25% in a mix of 1:1.5:3. According to them, there is no substantial increase in tensile strength due to the addition of RHA while there is a marginal improvement in flexural strength with 10 to 25% RHA replacement levels. They concluded that RHA is good for structural concrete at 10% replacement level.

Marthong (2012) [9] found that shrinkage of RHA concrete is similar to the pure cement concrete in all grades of OPC. Also, it is detected that, water absorption decreases up to 20% replacement of cement by RHA and inclusion of RHA as partial replacement of cement slightly improves the durability when exposed to sulfate environment. Author suggested that, the use of RHA as partial replacement of cement up to a maximum of 10% by volume in all grades of cement is having good compressive strength performance and durability.

Muthadhi et al (2013) [10] prepared four concrete mixtures to identify the effect of RHA (added as partial replacement of ordinary Portland cement from 10 to 30%) on performance characteristics of concrete. They found that, the durability of RHA concrete was on the higher side for all doses, compared with the nominal mixtures. Therefore, by considering the maximum strength, cost effectiveness, and performance characteristics, 20% replacement of cement by RHA addition was concluded as optimum dosage in concrete making.

Nair et al. (2013) concluded that incorporation of RHA in concrete results in improved compressive strength and flexural strength. A slight increase in bond strength was also reported. RHA-High strength concrete showed a reduction in density compared with conventional concrete.

Rajput et al (2013) [11] studied strength characteristics of cement mortar in which RHA was used as partial replacement (5% to 30% by weight of cement) of ordinary Portland cement (OPC). From the test results author have concluded that, if approximately 10% of cement is replaced by RHA, there is not any significant depreciation in the compressive strength at 28 days and thus the RHA can be used as partial replacement of cement in the regions where the material is locally available.

Many researchers [12–16] have concluded that, the optimum replacement level of rice husk ash is to be 0 to 20% for M30 grade of concrete and the pozzolanic activity of rice husk ash is not only effective in enhancing the concrete strength, but also helpful in improving the impermeability characteristics, durability and other properties of concrete. Various studies have carried out by using RHA and colloidal nano silica (CNS) as a supplementary cementitious material out of which, Hou et al. (2012) [17] investigated the influences of adding colloidal nano SiO_2 (CNS) on fly ash hydration and microstructure development of cement-fly ash pastes. They concluded that the early age strength gains of a CNS added FA-cement paste is probably due to the acceleration effect of nano SiO_2 on both cement and fly ash hydration.

Kontoleontos et al. (2012) [18], concluded that colloidal nano silica behaved not only as a filler to improve cement micro-structure (porosity decrease), but also as a promoter of pozzolanic reaction. Among four ages and three sets of mix proportions, they consider optimal mix proportion is the set of 4% NS addition, which presented the highest compressive strength of 78.9 MPa, after 28 days of curing. They also concluded that at early ages, the main hydration component was C3S, whereas silica nanoparticles provided nucleating sites for the precipitation of hydration products (especially $Ca(OH)_2$ and colloidal nano silica slightly increased the strength of the ultra-fine cement, mainly because of the packing effect and at later ages, nano silica modified the internal structure of the C-S-H gel, increasing the average chain length of the silicate chains, leading to a denser structure and $Ca(OH)_2$ evolution was diminished due to the pozzolanic reaction, whereas the large pores were partially or completely filled with hydration products (especially secondary C-S-H) and thus the enhancement of the compressive strength at later ages was due to the consuming of $Ca(OH)_2$ by nano silica. Another experimental study was carried out by Quercia et al. (2012) [19], in which they have applied two different types of nano-silica in self-compacting concrete, both having similar particle size distributions but produced in two different processes (fumed powder silica and precipitated silica in colloidal suspension). From the results of the fresh state behavior of SCC they found that concrete with addition of 3.8% of nano-silica (based on the mass of cement) shows similar flowing and viscosity behavior as the reference mix without nano-silica. They also found small differences in the reactivity at early age for both types of nano-silica while colloidal type shown more reactivity at early age, which influenced all the final SCC properties.

Hou et al. (2013) [20] carried out experiments, by incorporation of fly ash and CNS. Each increase the viscosity of cement paste however, there exists a threshold value for the CNS dosage above which the viscosities of fly ash-cement pastes become equal to or less than those of cement pastes without fly ash and the incorporation of fly ash offsets the decrease in flow ability of mortars caused by CNS.

Rathi et al. (2014) investigated the influence of colloidal nano SiO_2 (CNS) addition along with P-100 grade of fly ash on hydration of cement paste and compressive strength of cement mortar. From the result they reveal that, fly ash hydration is accelerated by CNS at early age thus, enhancing the early age strength of materials. They concluded that initial and final setting time of cement paste goes on decreasing, which indicates the accelerating effect of CNS on cement hydration, when CNS is added the initial setting time (IST) and final setting time (FST) of cement and fly ash paste was significantly shortened although, fly ash delays the hardening of paste, the addition of CNS can greatly offset this effect. It is observed from literature that in RHA concrete, the level of replacement of cement was restricted to 10%–20% on the basis of workability, strength, impermeability characteristics, and durability. Ordinary Portland Cement (OPC) was replaced by RHA at various percentages, so as to arrive at optimum dose of RHA. Few literature is available indicating the replacement of cement by both RHA and CNS. In this study, cement was first replaced by RHA and based on optimum dosage of RHA, further replacement of cement with CNS was made. CNS not only accelerates the pozzolanic activity of RHA but also enhancing the other properties such as durability, strength and workability etc. Hence this study promotes the use of RHA in high strength concrete as a sustainable cement replacement material.

RESEARCH SIGNIFICANCE

It is evident from past studies that; significant amount of work has been carried out either on rice husk ash, powder nano silica (PNS) and CNS, apart from CNS, more experiments have been carried out on PNS. In this study, CNS has been used instead of PNS. There are several reasons behind using CNS depending upon its properties such as state, dispersion and health hazards. Nanosilica particles suspended in water whereas PNS is in dry state. Regarding the issue of dispersion, colloidal Nano silica gives evenly dispersion and can be used in place of Nano silica powder while PNS does not gives proper dispersion. Also, CNS is not dangerous to health when inhaled while PNS is dangerous for breathing system when inhaled. More literatures available in which effect of powder nano silica was studied in rice husk ash concrete. But there are problems of using powder nano silica such as, it does not give proper dispersion and also dangerous for breathing system when inhale. To solve this problem colloidal nano silica can be use which gives evenly dispersion and it is not dangerous to health when inhale. So, in this study, effect of colloidal nano silica on high strength rice husk ash concrete was studied. Colloidal nano silica gives uniform dispersion in comparison with powder nano silica when added in cement paste and also it overcomes the disadvantage of low early strength of rice husk ash concrete by accelerating pozzolanic action.

MATERIALS

In view of the proposed experimental study, the materials such as rice husk ash, colloidal nano silica, superplasticizers, ordinary Portland cement, aggregates (Metal 10, Metal 20) and sand were used.

Cement

The cement used in the said investigation comprised of Ordinary Portland Cement (Ultratech Cement of 53 Grade). The chemical composition and physical properties of the OPC obtained from the suppliers are shown in Table 1.

Table 1. *Characteristics of cement.*

Normal consistency (IS:4031 Part IV)	
Required water for normal consistency	110 ml
% of Normal consistency	27.5%
Setting time (IS:4031 Part V)	
Initial setting time	150 min (maximum 30 min)
Final setting time	225 min (maximum 600 min)
Specific gravity (IS:4031 Part II)	3.14
Specific surface (fineness) (IS:4031 Part II)	310.83 (maximum 225 cm^2/gm)
Compressive strength	
3 Days	27 MPa
7 Days	37 MPa
28 Days	53 MPa

Coarse Aggregate

Coarse aggregates of 20 and 10 mm nominal size having specific gravity of 2.79, confirming to (IS: 383-1970) was used in this investigation.

Fine Aggregate

Gujrat sand of zone-I, having specific gravity of 2.07, confirming to (IS: 383-1970), was used in this investigation. The properties and sieve analysis result of fine aggregate are shown in Table 2.

Table 2. *Properties and sieve analysis result of fine aggregate.*

Particulars		**Test result**	
Grading zone		I	
Specific gravity		2.07	
Dry loose bulk density		1401.34 kg/m^3	
Water absorption		0.81%	
Moisture content		0%	
Silt content		2.76%	
Fineness modulus		3.14	
Sieve analysis of sand			
Sieves	% weight retained	Cumulative % retained	Cumulative % passing
4.75 mm	0	0	100
2.36 mm	0.98	0.98	99.02
1.18 mm	37.07	38.05	61.95
600 µ	40	78.05	21.95
300 µ	19.51	97.56	2.44
150 µ	1.95	99.51	0.49
Pan	0.49	100	0

Superplasticizer

The superplasticizer used, namely Master Glenium SKY8233, was procured from BASF Pvt. Ltd. Turbhe, Mumbai, Maharashtra (India). The superplasticizer used is polycarboxylic based high range water reducing (HRWR) admixture. The properties are shown in Table 3.

Table 3. *Properties of master glenium SKY8233.*

Particulars	**Values**
Chemical content	Poly carboxylic ether
Aspect	Light brown liquid
Specific gravity	1.08
Chloride content	<0.2%
Recommended dosage	500–1500 ml per 100 kg cement
Solid content	30% by weight
Compatibility	All types of cement
pH	>6
Reference specification	IS 9103:1999

Rice Husk Ash (RHA)

RHA was procured from N. K. Enterprises, Jharsuguda-768201, Orissa State, India. RHA of 2.30 specific gravity and 25 µ size was used.

Colloidal Nano Silica (CNS)

Colloidal Nano Silica was procured from BEE Chems, Kanpur-208022, India. The properties as shown in Table 4.

Table 4. *Properties of colloidal nanosilica.*

Color	Specific gravity	pH value	Solid content	Particle size	SiO_2 content
White	1.12	10.11	39%	8–20 nm	99.1%

METHODOLOGY

The present study involves a series of various tests performed on different materials to arrive at certain physical properties. The various experimental tests that were conducted during the present study include specific gravity of aggregates and crushed sand, water absorption of aggregates and crushed sand as well as compressive strength, workability, split tensile strength of concrete. Concrete mixes of grade M60 were made using OPC. Replacement of cement was made using RHA at 5, 10, 15%. The 10% RHA was taken as optimum dose on the basis of workability and compressive strength. To this 10% RHA concrete, effect of 1, 2, 4, and 6% CNS addition were study by workability, compressive strength and split tensile strength. The concrete mixes were tested for compressive strength and split tensile strength at 3 days, 7 days and 28 days of curing, respectively. The concrete mixes for the present study comprised of ordinary Portland cement concrete and seven mixes of RHA and CNS concrete mixes, to investigate their effect on compressive strength, workability and split tensile strength. After several trials, cement content of 457 kg/m^3 and water-binder ratio of 0.35 were finalized based on 28 days' compressive strength gain of HPC mix and desired workability properties (slump flow). Thus, for making HPC mixes the mix proportion was finalized as follows:

- W/C: 0.35
- Cement: 457 kg/m^3
- Coarse aggregate: 1158 kg/m^3
- Fly ash: 700.19 kg/m^3
- Superplasticizer: 1%

RESULTS AND DISCUSSION

The various tests which were conducted on fresh as well as hardened concrete like workability, compressive strength and split tensile strength have been presented and discuss in brief.

Workability

Table 5 gives the workability by slump cone test of conventional mix, with 5, 10 and 15% RHA replacement and further 10% replacement of RHA, with addition of 1, 2, 4, 6% CNS was made.

Table 5. *Workability results.*

Description	Mix ID
Conventional mix	CM
RHA Mix	R5M
	R10M
	R15M
RHA+CNS Mix	R10C1M
	R10C2M
	R10C4M
	R10C6M

Figure 1 shows workability of different mixes, from Figure 1, it has been observed that on replacement of cement with 5 and 10% RHA, the slump was decreased by 65.52% and 70.69%

with respect to conventional mix also 15% RHA replacement gives zero slump.

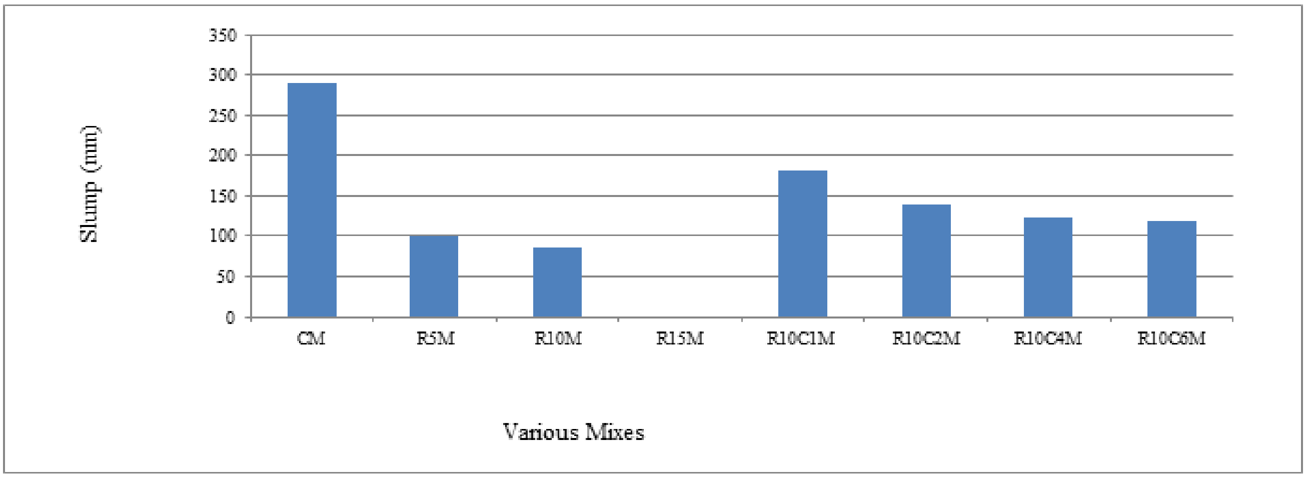

Fig. 1. *Workability of different mixes.*

In the present study, workability was considered as one of the important factor for deciding the optimum dose of RHA. Therefore, from above experimental data, the optimum dosage of RHA was considered as 10%. Further, the replacement of 1, 2, 4, and 6% CNS on 10% RHA with cement, decreases the workability consistently. This may be because of the nano silica is finer than the cement, the specific surface area increases as the nano silica content increases also when particle size gets finer it needs more water to facilitate the movement of particles which results in decrease in workability.

Compressive Strength

Figure 2 shows variation in compressive strength of cubes at 3, 7, and 28 days of curing.

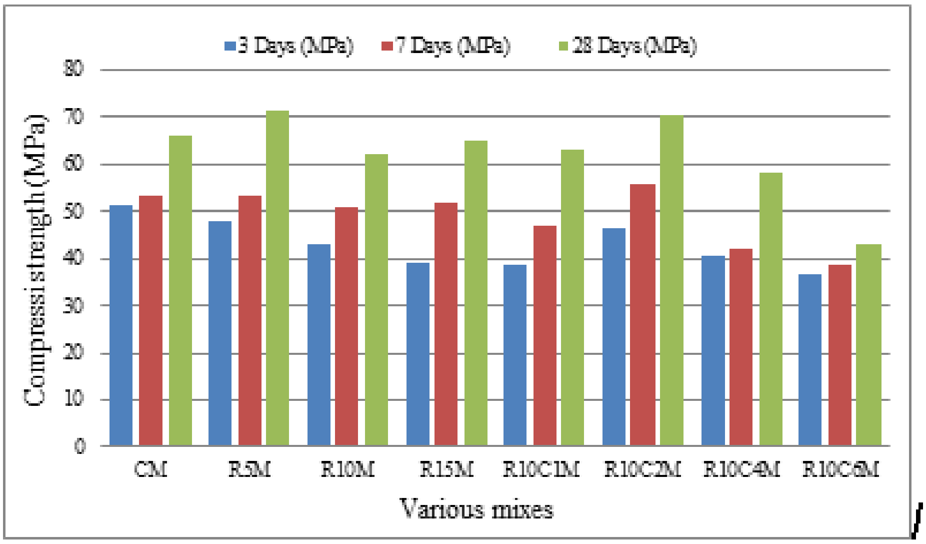

Fig. 2. *Variation in cube compressive strength at various ages.*

From Figure 2, it has been observed that at 3 days, the compressive strength of 5, 10 and 15% RHA replacement mix were decreased by 7.47%, 16.86% and 24.48% with respect to conventional mix. At 7 days, the compressive strength of 5, 10 and 15% RHA replacement mix were decreased by 0.36%, 4.78% and 3.17% with respect to conventional mix, and at 28 days, the compressive strength of 5% RHA replacement mix was increased by 8.13% while it was decreased by 5.83%, 1.17% for 10, and 15% RHA replacement mix with respect to conventional mix.

Further, replacement of 1, 2, 4 and 6% of CNS in 10% RHA shows that compressive strength increases at 2% CNS replacement while compressive strength decreases at 1, 4 and 6% replacement of CNS with RHA.
Also, it has been observed that compressive strength at 28 days, at each replacement of RHA was slightly higher than 60 MPa this may be because of CNS is an excellent source of pozzolanic reaction, with its small particle size and surface chemistry making it among the most reactive pozzolan sources known. CNS reacts with calcium hydroxide (by-product of the cement/water hydration process) in the pore space to form secondary C-S-H, reducing the size of capillary voids and pores, which leads to a denser and more homogeneous structure, greatly improving the mechanical properties of the concrete.

Initial and Final Setting Time of Cement
Concrete mix with CNS, sets faster than conventional and RHA mix. This is because CNS accelerate cement hydration (Hou et al, 2013) and this is investigated through Vicat Test (for determining initial and final setting time of cement) experiment whose result is shown in Table 6.

Table 6. *Initial and final setting time of cement.*

Setting time	OPC	OPC+10%RHA	OPC+10%RHA+2%CNS
Initial setting time (min)	128	106	92
Final setting time (min)	200	164	122

Figure 3 shows the graphical representation of effect on initial and final setting time of cement through Vicat's apparatus.

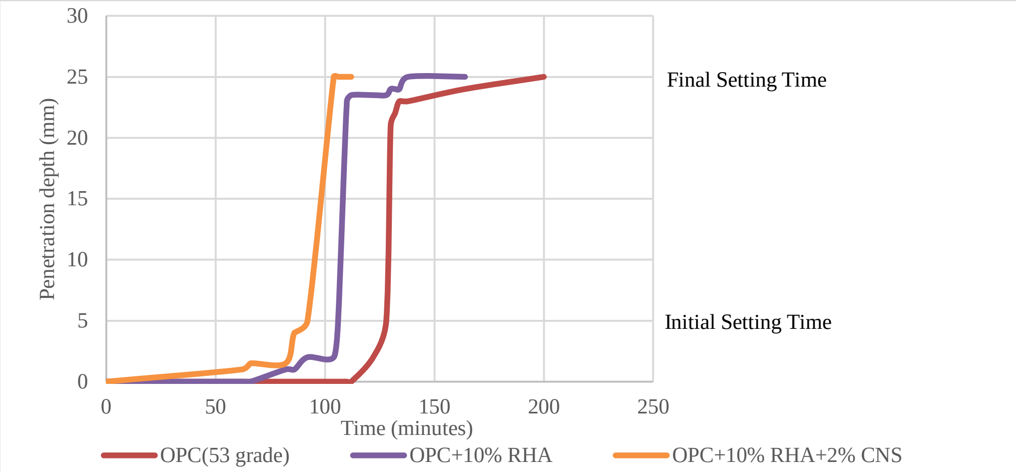

Fig. 3. *Effect on initial and final setting time of cement.*

From Figure 3, it has been observed that, replacement of 1, 2, 4 and 6% of CNS in 10% RHA shows that compressive strength increases at 2% CNS replacement while compressive strength decreases at 1, 4 and 6% replacement of CNS with RHA. This may be because of addition of 2% CNS in 10% RHA replacement accelerate the hydration process, and this is investigated through Vicat's apparatus through initial and final setting time of powder content.

From above graphical representation, it has been observed that, the initial setting time (IST) and final setting time (FST) of cement paste goes on decreasing, which indicates the accelerating effect of CNS on cement hydration. CNS greatly shortened the IST and FST of all paste, when CNS Is added the IST and FST of cement + RHA paste were significantly shortened although RHA delays the hardening of paste the addition of CNS can greatly offset this effect.

Split Tensile Strength

Figure 4 shows variation of split tensile strength with respect to percentage of NS and RHA.

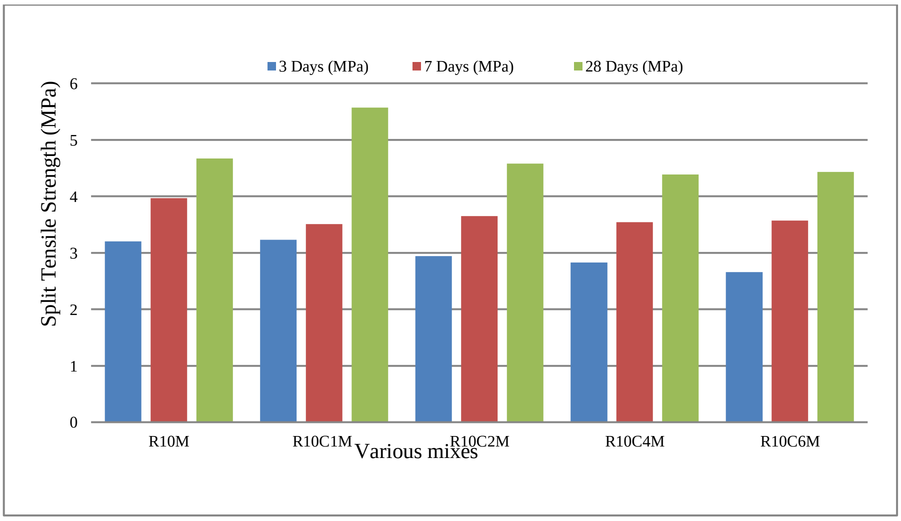

Fig. 4. *Variation in split tensile strength at various ages.*

From Figure 4, it has been observed that, at 3 days and 28 days curing, the split tensile strength was increases by addition of 1% CNS in 10% RHA, while it was decreases in addition of 2, 4, and 6% CNS in 10% RHA replacement respectively and at 7 days, the split tensile strength was decreases for 1, 2, 4, and 6% CNS addition in 10% RHA, respectively.

Hence out of all the combinations, the highest strength with 1% CNS in 10% RHA replacement with cement is obtained. This is due to nano silica fills the pores in the concrete both CNS and RHA involves in the pozzolanic reaction with C-H and forms stable C-S-H bond between the matrix and the aggregates thus reducing the porosity and makes concrete dense which in turn increases the tensile strength of concrete.

CONCLUSİON

An experimental research work has been carried out to understand the behaviour of CNS and RHA on workability and strength properties of concrete. Based on the test results following conclusions can be drawn:

- Replacement of cement with RHA decreases the workability consistently.
- 10% RHA replacement gives compressive strength slightly more than 60 MPa at 28 days. Therefore, considering 10% RHA as optimum dosage on the basis of workability and strength.
- The workability increases by adding 1, 2, 4, and 6% CNS on optimum of 10% RHA replacement.
- The compressive strength of 2% CNS addition in 10% RHA replacement mix was consistently increased at 3,7, and 28 days with respect nominal mix.
- The split tensile strength was increased in case of 1% CNS, while it was decreased in case of 2% CNS on replacement of 10% RHA at 3, 7 and 28 days of curing, respectively.
- It has been observed that by adding CNS, concrete sets faster as compared to RHA mix solely.

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