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Effect of Partial Replacement of Slag and Nano Silica Infused Slag on Properties of Concrete

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Abstract: Investigations were carried out on the changes in properties of concrete when steel slag is used in concrete in its normal form and after modifying its properties by infusing it with nano silica. The sand is replaced by steel slag and modified steel slag by 10%, 20% and 30% in M30 grade concrete. Tests results on compressive strength and workability of concrete revealed that, compressive strength of concrete cubes after 28 days increased by 25.4%, 26.4% and 45.2% for 10%, 20% and 30% respectively after replacing sand by steel slag. After modification of steel slag properties by infusing it with nano silica, the 28 days compressive strength was observed to be increased by 38.19%, 35.80% and 27.89% for 10%, 20% and 30% as compared to traditional concrete mix respectively after replacement. Infusing steel slag with nano silica increased the compressive strength of concrete mix by 20.17%, 25.74% and 49.64% for 10%, 20% and 30% respectively when compared to normal steel slag concrete mix. It was also observed that using steel slag in concrete mix also influences on water consumption in concrete mix. Workability tests conducted using 0.45 and 0.5 w/c ratio and the inference was that the workability increased with the increase in percentage of steel slag but workability decreases with the increase in percentage of modified steel slag.

Abbreviations: CS: Compressive strength, **NS**: Nano silica, **INSS**: Infused Nano Silica Steel slag, FA: Fine aggregate, **CA**: Coarse aggregate, **PSD**: Particle size distribution, **TC:** Traditional concrete, SSC: Steel slag concrete,

Keywords: Specific gravity, Compressive strength, Infusion, Nano silica, steel slag, workability, Particle size distribution

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INTRODUCTION

Concrete is the main heterogeneous composite material used in construction industry, whose main ingredients are cement, FA, CA, water. FA and CA are derived from natural resources which are depleting at a alarming rate due to infrastructure projects. Therefore searching for alternatives for natural aggregates is significantly gaining momentum all over the world. Industrial solid wastes with moderate to high specific gravity are considered to be useful in making concrete.

The utilization of solid wastes in construction at low cost and reducing load on natural resources is one of the innovative ideas globally accepted (P. Ziemkiewicz 1998; Singh, S.P. et al., 2013) for sustainable development. Globally, the estimated quantity of solid wastes generation was 12 billion tons in the year 2002 (Pappu et al., 2007). Among this amount, 11 billion tons were industrial solid wastes and 1.6 billion tons were municipal solid wastes and likely to touch 19 BTY^{-1} by 2025 (Yoshizawa et al., 2004). Asia contribute 4.4 BTY^{-1} of solid wastes with 6% share from India (Yoshizawa et al., 2004; CPCB, 2000) and Malaysia contributes 150000TD^{-1}.The disposal of these wastes has become a major environmental problem in Malaysia and thus the possibility of recycling the solid wastes for use in construction materials is of increasing importance. (Pappu et al.,2007).Similarly, the recycling of hazardous wastes for use in construction materials and the environmental impact of such practices have been studied for many years (Cyr et al., 2004). Steel slag (SS) is one of such solid wastes (Caijun Shi 2004), the average SS generated data on plant wise in 2009-10 and 2010-11 are given in **Table 1.** SS finds application in various construction activities **Table 2** which is a by product of steel industry. For bulk concrete uses, like large foundations, high density concrete (nuclear applications) and marine structures, SS has some merit. When considering SS for structural concrete applications, special care must be taken to confirm that the aggregate is totally stable, and that the Alkali Silica Reaction potential is within specified limits. SS has been used extensively around the world as: railway ballast, trickling filter bed media, pipe bedding, water course protection, land reclamation, bulk fill embankments and gabion stone. (Kevin A. H 1996, J.W. Lim et al 2016).

From the literature survey we have envisaged that there is significant application of SS in civil engineering applications. Whereas further use of SS by infusing with NS is yet to be studied using pin point experiments.

Therefore the present study involves experimental investigations on properties of concrete by using of SS and NS infused SS as a partial replacement to FA.

MATERIALS AND METHODS

Procurement of research material

- Steel slag was procured from Karthik Inductions; Rukmini & Rama (RR) steels Pvt. Ltd., Kundaim Industrial Estate. Goa (**Plate 1**).

- Nano silica was procured from ASTRRA chemicals, Chennai, India (**Plate 2**).
- CA, FA, Cement were procured from locally available dealers and maintained in the civil engineering laboratory.

Specific Gravity test was conducted as per IS: 2386 (Part III & IV) - 1963 The Particle size distribution of SS, and infused SS was obtained by running sieve analysis as per IS 2720 (part IV) -1985.

Infusion process:

The experimental set up consists of beakers of Size 500 ml were taken and in each 200 g of SS was taken and varied proportions of NS was added to each beaker and water of 85ml and the set up as preserved for 3 days. The INSS is placed in Plate 3.

Preparing the M30 concrete with SS and INSS and carrying out CS experiments.

Concrete Mix design for M 30 grade concrete

The Mix design was carried out in accordance with IS 10262-2009 with water cement ratio of 0.5.
Standard concrete cubes of size 150 x 150 x 150 were prepared.
Workability test was carried out in accordance with IS 1199 - 1959 curing of cubes was carried out in a water tank temporarily built water tank specially constructed using a polythene placed inside the used concrete cube wall constructed in a rectangular fashion of size 2m x 1m x 1m depth.

The CS was determined out using a universal testing machine in accordance with IS 516:1959. The results are tabulated and placed in results and discussed for the comparison with other researchers.

RESULTS AND DISCUSSION

The results of proportions of SS : WATER : NS are place in **Table 4**

The comparison of specific gravity of the materials indicates that the SS well fits as a material to be replaced in the concrete as FA and CA..

PSD of the FA and crushed SS passing through the 4.75mm sieve tested were confirming to zone II of IS code 383-1970.Which is most favourable for concrete making. The PDS of FA and SS is placed in **Fig.1**

The workability test indicates that as the percentage of SS increases the slump value increases. The slump value for SSC is nearly same as TC at 10% replacement and gradually increases for 20% and 30%. The changes are consistent for w/c 0.5 but there is increase in workability **Fig 2**. The results are in line with Pofale A D and Mohammed N (2012).

The compaction factor result indicates that the compaction factor increases with increase in percentage of SS in concrete. The graph also indicates that at w/c ratio 0.45 workability is medium and at w/c 0.5 workability is high Fig 3.

From the Comparison of slump values for TC and modified SS in concrete placed in fig 4. it can be observed that as the percentage of INSS as FA increases the workability for 10% compared to TC but decreases for 20% and 30% compared to 10% but increased when compared to TC for both 0.45 and 0.5 w/c ratio. Higher workability obtained at 0.5 compared to 0.45 w/c ratios.

Compaction factor increases with increase in INSS percentage in concrete compared to TC but comparing to 10% replacement the compaction factor decreases for 20% and 30 % replacement Fig 5.From the graphs obtained for slump and compaction factor for different mixes of concrete with SS and INSS, it can be inferred that the workability reduces as the percentage of INSS increases in the concrete mix, and the workability increases as the normal SS percentage of replacement increased.

It can be inferred from Fig.6 that as the percentage replacement of SS increase in concrete as FA the compressive strength of concrete is increasing. Further trial mixes to be carried out to know the CS after complete replacement of FA by SS results in line with Khalid Raza, et al (2014).

Replacing INSS in concrete increased the strength in concrete upto 10% replacement of FA but further the CS decreased Fig.7.

The comparison of CS of SSC and INSS concrete with TC mixes Fig 8. The CS of both mixes has increased compared to TC. CS of SSC mix is higher than that of INSS mix. CS of 30% replacement of FA by SS in concrete has obtained highest strength at the end of 28 days. From the graph it can be inferred that replacing not more than 10% of infused SS is favourable and not more than that. Gurjeet Singh, et al 2015 has replaced with 100% SS and have got results in confirmity with us.

CONCLUSION

From our research work we conclude the following:

- Using steel slag as fine aggregate increases the strength in concrete by 25.4%, 26.4% and 45.29% for 10, 20 and 30 percent respectively after 28 days of curing
- After infusing SS with nano silica (SiO_2) strength of concrete was observed to be increased by 38.19%, 35.80% and 27.89% for 10, 20 and 30 respectively after 28 days of curing.

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Table 1: Plant wise Average Generation of Slag in 2009-10 and 2010-11 in India.

Steel plant	Production in year (In kg/aud of hot metal)	Production in year (In kg/aud of hot metal)
Bhilai Steel Plant, Durg, Chhattisgarh.	395	399
Bokaro Steel Plant Bokaro, Jharkhand	380	370-380
Rourkela Steel Plant, Rourkela, Odisha	NA	NA
Visvesvaraya Iron & Steel Plant, Bhadravati, Karnataka.	318	NA
Durgapur Steel Plant, Durgapur, West Bengal.	NA	NA
IISCO Steel Plant, Burnpur, West Bengal.	503	NA
IDCOL Kalinga Iron Works Ltd, Barbil, Odisha.	NA	0.380

JSW Steel Ltd, Bellary, Karnataka	NA	NA
NeelachalIspat Nigam Ltd. Kalingnagar, Duburi, Odisha	273	287
RashtriyaIspat Nigam Ltd, Visakhapatnam, Andhra Pradesh.	310	320
Tata Steel Ltd, Jamshedpur, Jharkhand	279	274
VISA Steel Ltd. Kalingnagar,Odisha.	16	NA

Following table gives utilization of SS in construction industry in various countries.

Table 2: Country wise application of SS in construction industry

Country	**Applications of SS in construction industry**	**Reference**
Malaysia	Road; Cement ;Rail Ballast; Bridge	Oluwasolaa, et al 2014, Patil S et al 2016
Turkey	Road materials; Lime stabilization	Kavak A et al 2016
India	Replacement of CA;	Khalid R, et al 2014,
	Embankments; Flexible pavements	Patil S S, et al, 2016
	Sub grade pavements	Yildirim I Z et al 2009
	Fertilizers, hydraulic engineering, metallurgical purpose	Singh S P and Murmu M
Soudi Arabia	Sub base pavements	Khan et al 2002
New Zeland	Removal of storm water contaminants	Taylor M 2006
China	Cement	Liqian Qi et al 2015
Italy	Replacement of CA in concrete	Monosi S, et al ()Md. Safiuddin 2010, Mahmoud A, 2012

Table 3: Applications of nanotechnology in construction industry

India	concrete for reducing segregation in self compacted concrete,	Patel Abhiyan S et.al (2013)
	The use of copper nano-particles in low carbon HPS is remarkable, The use of nano sensors in construction phase to know the early age properties of concrete is very useful, Its use in water purification system by replacing the use of granulated particles of carbon in filtration with purifiers like Nano Ceram-Pac (NCP).	Amit Srivastava, Kirti Singh (2011)

	Nano cement, Nano composites	Ali Akbar Firoozi, Mohd Raihan Taha, Ali Asghar Firoozi, (2014)

Table 4: Proportions of SS : WATER : NS

SS (grams)	Water (ml)	NS (grams)
200	85	0.2
200	85	0.4
200	85	0.6
200	85	0.8
200	85	1.0

Table 5: Properties of ingredients used in concrete

Material	Specific gravity	Normal consistency	Fineness index	Sieve analysis
Cement	3.16	35%	2	NA
FA	2.774	NA	NA	Zone II
CA	2.763	NA	NA	NA
SS	2.36	NA	NA	NA
NS	1.35	NA	NA	NA
INSS*	4.3	NA	NA	Zone II

*200gms:8ml5:0.6gms ; NA not applicable

Table 6: Percentage increase in CS of SS compared to TC

Curing in days	TC	Steel slag			Increase in compressive strength		
		10	20	30	10	20	30
0	0	0	0	0	0	0	0
7	29.481	42.963	29.852	32.593	45.72864	1.256281	10.55276
14	32.365	44.593	35.975	40.198	37.77846	11.15349	24.19896
28	38.133	47.852	48.222	55.407	25.48563	26.45688	45.29915

Table 7: Percentage increase in CS of INSS mix compared to TC

Curing in days	TC	Steel slag infused with NS N/mm^2			Increase in compressive strength		
		10	20	30	10	20	30
0	0	0	0	0	0	0	0
7	29.481	45.037	40.222	39.852	34.539	26.703	26.022
14	32.365	45.926	42.123	40.198	29.527	23.165	19.484
28	38.133	47.704	45.926	40.889	20.062	16.968	6.739

Table 8: Increase in strength of NSSS mix compared to normal SS mix

Curing in days	SS	NSSS	% Increase
	% Increase for 10%		
7	42.963	15.329	64.321
14	44.593	23.247	47.867
28	47.852	38.199	20.173
	% Increase for 20%		
7	29.852	5.193	82.603
14	35.975	16.319	54.639
28	48.222	35.806	25.747
	% Increase for 30%		
7	32.593	4.312	86.769
14	40.198	12.310	69.377
28	55.407	27.899	49.648

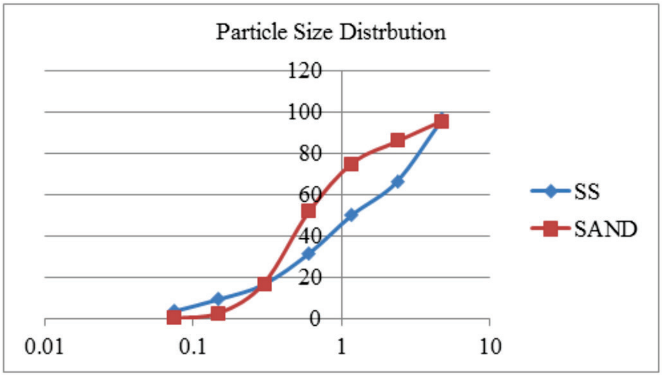

Fig. 1: Particle size distribution of FA and SS

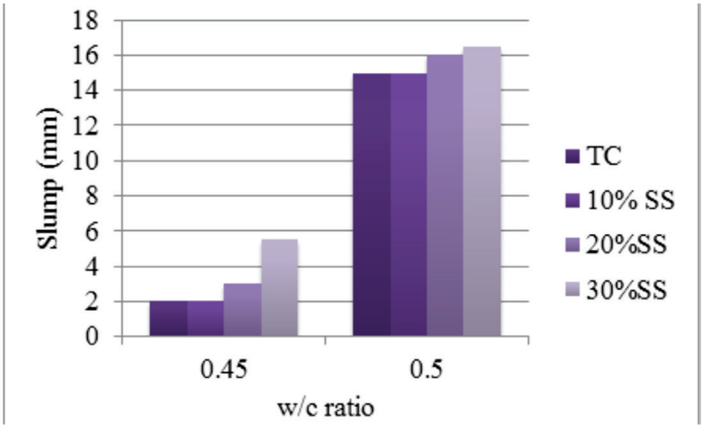

Fig. 2: Graph Showing Slump Values For SS

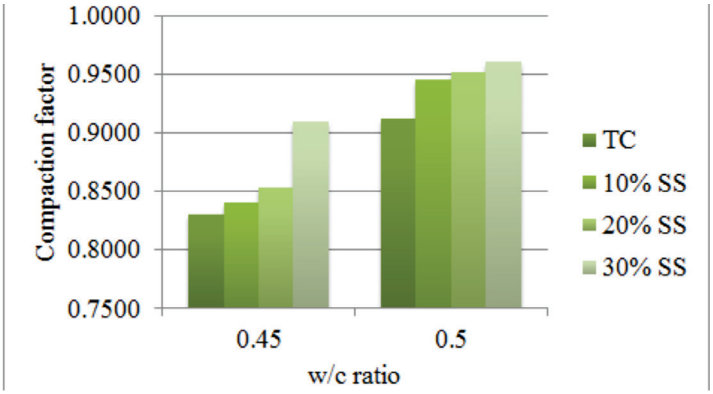

Fig. 3: Graph showing compaction factor of TC and SSC

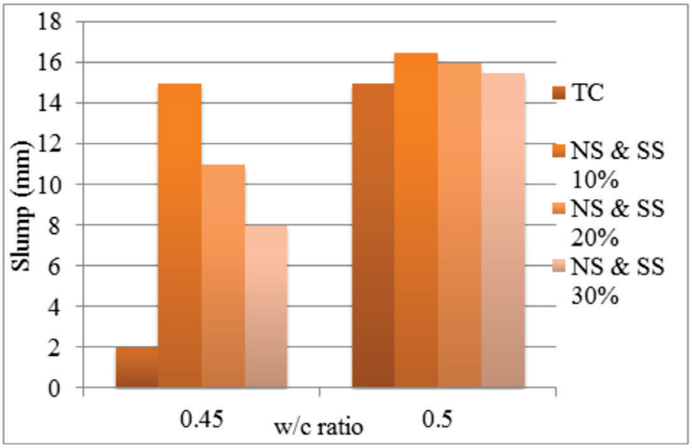

Fig. 4: Comparison of slump values for TC and modified SS in concrete

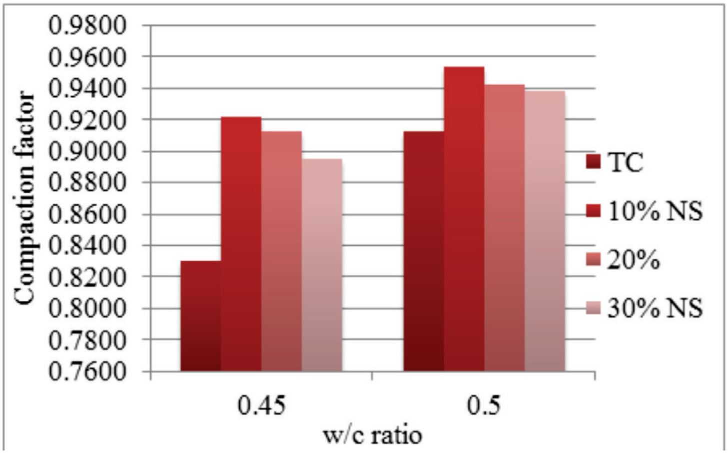

Fig. 5: Compaction factor values for modified SS in concrete

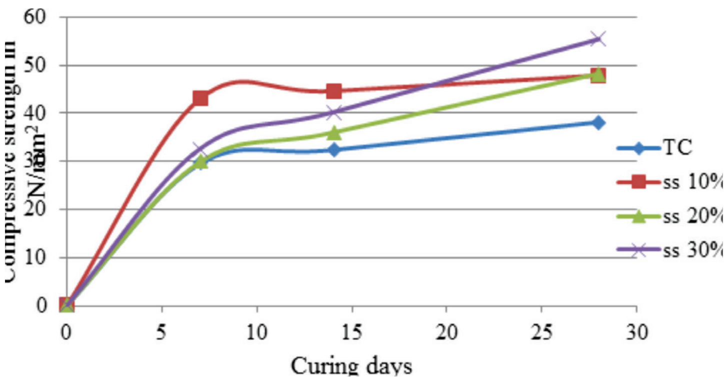

Fig. 6: Variation in CS of TC, 10%, 20% and 30% mixes

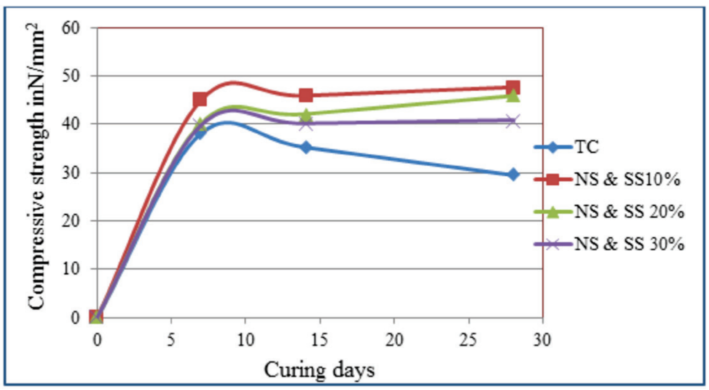

Figure 7: Graph showing variations in CS of TC, 10%, 20% and 30% NSSS mixes

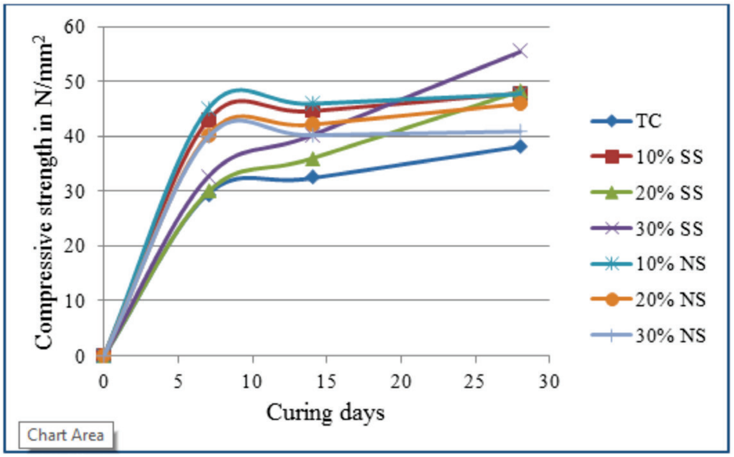

Figure 8: Graph showing CS variation for TC, normal SS and NSSS mixes.

Plate 1: Steel slag

Plate 2: Nano silica

Plate 3: Infused SS kept for air drying.