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

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 (SiO₂) 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, Bhadrawati, Karnataka. | 318                                        | NA                                         |
| Durgapur Steel Plant, Durgapur, West Bengal. | NA                                         | NA                                         |
| IISCO Steel Plant, Bumpur, West Bengal. | 503                                        | NA                                         |
| IDCOL Kalinga Iron Works Ltd, Barbil, Odisha. | NA                                         | 0.380                                      |
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; Embankments; Flexible pavements | Khalid R, et al 2014, Patil S S, et al, 2016 |
|                | Sub grade pavements                        | Yildirim I Z et al 2009 |
|                | Fertilizers, hydraulic engineering, metalurgical 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. Saifiuddin 2010, Mahmoud A, 2012 |

Table 3: Applications of nanotechnology in construction industry

| Country | Applications of nanotechnology in construction industry | Reference                                      |
|---------|----------------------------------------------------------|------------------------------------------------|
| 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) |
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/mm² | 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 for 10% | % Increase for 20% | % Increase for 30% |
|---------------|----|------|-------------------|-------------------|-------------------|
|               |    |      |                   |                   |                   |
| 7             | 42.963 | 15.329 | 64.321            |                   |                   |
| 14            | 44.593 | 23.247 | 47.867            |                   |                   |
| 28            | 47.852 | 38.199 | 20.173            |                   |                   |
|               |      |      |                   |                   |                   |
| 7             | 29.852 | 5.193 | 82.603            |                   |                   |
| 14            | 35.975 | 16.319 | 54.639            |                   |                   |
| 28            | 48.222 | 35.806 | 25.747            |                   |                   |
|               |      |      |                   |                   |                   |
| 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
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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.