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On The Mechanical Aspects Concrete Containing Mill Scale

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***Abstract -** The current paper experimentally investigates the effects of partial replacement of fine aggregate by mill scale in concrete in varying proportions by weight. Mill scale was added by weight of fine aggregate with partial replacement of 0%, 10%, 20%, 30%, 40%, 50% and 60% and using Portland Pozzolana Cement in C20/25 grade of concrete. The physical and mechanical properties of concrete so produced were evaluated. The fresh concrete produced showed a drastic reduction of slump with increasing percentage replacement with 74% reduction at 60% replacement compared to the control mix. Further, the compressive, flexural and split tensile strength also showed a drop in strength by 34.5%, 27% and 19% with respect to control mix for 60% replacement respectively. From the microstructural studies, it could be concluded that mill scale acts as a filler material and can be used as partial replacement of sand effectively up to 40% by weight of cement in concrete.*

Keywords - *Mill Scale, concrete aggregates, physical and mechanical properties, durability, waste utilization.*

Article Highlights:

- Mill scale does not show lime reactivity and hence can be used for partial replacements of fine aggregates and not for replacement of cement in concrete.
- Mill scale is inert and hence is effective filler material resulting in denser concrete.
- Physical, mechanical and durability aspects of resulting concrete showed that replacements up to 40% of fine aggregate are possible.

I. INTRODUCTION

Recently, utilization of industrial wastes in concrete has received ample attention from researchers across the globe. Industrial wastes and by-products, consumed in concrete tend to modify the properties of concrete and also aid in reduction of environmental hazards. Research for such effective consumption of industrial wastes is particularly a very active field of research in Indian scenario. This could be attributed to the rapid growth of Indian economy due to industrialization, especially over the recent years. In this context, the steel industry of India needs a special mention. According to the reports of World Steel Association [1], in 2018, India ranked second in global crude steel production producing 106.5 Mt. Such a massive production of steel also leads to production of huge by-products and wastes. One such waste from the steel industry is Mill scale (MS). These are grayish blue, fine, flaky particles generally of size less than 1 mm [2]. The basic ingredients of MS are Iron (Hematite Fe_2O_3, Magnestite Fe_3O_4 and Wusite FeO), Silica and Alumina [2, 3]. It is obtained as a byproduct of steel hot rolling process. Every year, nearly 1.4 Million Tons of MS is produced in India [4].

Although, rich in Fe content (nearly 65-70%), MS is still largely considered as a waste because it gets contaminated with water and oil during the process of rolling and hence its recovery proves to be uneconomical. The present use of MS is thus, confined in the production of iron ore pellet or iron ore sinter, which in turn is used as a reducing agent in furnace for making iron [5]. It is also used as a raw material in granular refractory [6], in production of cement clinker [7], in alkali storage batteries [8] and in manufacture of colored glass [9].

II. BACKGROUND LITERATURE

Except in the production of cement clinker or as partial replacement of cement in mortar, no extensive work could be obtained in literature for possible consumption of MS in concrete. For example, the objectives of experimental investigations of Al-Otaibi [10] on cement mortar were towards replacement of cement by MS with 0%, 20%, 40%, 50%, 70% and 100% replacements. The compressive and flexural strength values were found to increase during the 3, 7 and 28 days, up to 40% replacement. Similarly, Pradip et al [11] manufactured alinite cement, which is an inorganic, low energy binding material. This was obtained by clinkering MS, along with fly ash, limestone fines, magnesite dust at 1150°C with calcium chloride as a sintering aid and discussed about the mechanical properties. The result of compressive strength was found to be comparable to OPC.

Limited literature could also be found on the utilization of MS as partial replacements of fine aggregates (FA). Perira et al.[12] used replacement levels 0, 10, 25 and 40% for a constant slump value of 110 mm with w/c ratios of 0.55 and 0.65. They reported a reduced compressive strength value of 20% and 23% respectively for both w/c ratios with reference to the control mix at 40% replacement. The water absorption of the concrete at all replacement levels was reported to be as high, with 57 and 44 % water absorption at 40% replacement for 0.55 and 0.65 w/c ratios respectively. The presence of contaminants was reported as the cause for reduced strength and increased water absorption values. It was concluded that there is a need for further experimentation before arriving at conclusive results for utilizing MS as alternate material for replacement of FA in concrete construction.

Singhal et al. [13] evaluated the physical and mechanical properties of cement mortar with 1:3 ratio and w/c ratio of 0.5 containing 0%, 20%, 40%, 60%, 80% and 100% replacements levels of MS. An increased water demand for mortar containing MS was reported. The X-ray analysis of the MS sample used in the investigation and presented in the paper showed diffused wide peaks indicating improper grinding of MS for powder diffraction. Hence, the peaks of Hematite, Magnestite, Wusite, could not be considered accurate. Further, the peaks of Silica and Alumina were not indicated. The need for proper XRD analysis cannot be ignored in such studies especially due to the presence of contaminants, which may affect the strength parameters. Nevertheless, the work indicated an increasing trend of density values with increasing MS %. This study concluded stating 40% replacement to be optimal.

From the above discussions, it could be observed that although some of the available literature [10-13] suggests the possibility of MS as alternate material in concrete, as far as strength is concerned, the pozzolanic activity of MS and the durability aspects of resulting mortar/concrete are currently not fully understood. While the pozzolanic activity decides whether MS can be used to replace cement or fine aggregate, durability tests assist in contemplating the longitivity of the structure. In an attempt to answer these questions, literature pertaining to use of similar steel industry by-products/wastes in concrete were studied. These included steel slag [14] and electric arc furnace slag [15-18]. These by products were selected due to closer proximity of chemical composition with MS.

Li et al. [14] investigated the mechanical properties of concrete containing different types of steel slag as replacement of cement. Specimen for testing the mechanical properties consisted of 10%, 20%, 30% and 40% replacement by mass of cement. The compressive and flexural strengths were found to decrease with increase in slag content.

EAF consists of FeO, Fe_2O_3, Silica and Alumina and has particle size 4.75 mm and down, while MS has similar composition with a particle size 1 mm down. Both EAF and MS are flaky in nature. Several researchers have studied the use of Electric Arc Furnace (EAF) slag as binder material or as replacement of FA. For example, the experimental investigation of Manso et.al [15] focused on the partial replacements of FA in concrete. The target mean strength for the design was 30 MPa which could be achieved at 50 % replacement of EAF in 28 days. The sample also exhibited low permeability. The durability of concrete containing EAF was also reported to be satisfactory via leaching and accelerated aging tests. Additional studies on the effects of EAF on re-bar compatibility and effects of admixtures were recommended in this work. Muhmood et al. [16] also investigated the cementitious and pozzolanic behavior of EAF slag. They reported that EAF can replace cement in concrete upto 15% by weight of cement without much loss of compressive strength of the resulting concrete. The laboratory studies of Zhao et al. [17] emphasized the need for proper grinding of steel making slag and confirmed good physical, mechanical and durability properties.

Recently, Lee et.al [18] investigated use of EAF as cement binder. Initial and final setting, shrinkage, compressive and split- tensile strength of EAF concrete were examined. A reduction in slump with increasing EAF content was reported. Slower strength gain was observed in comparison to OPC. Shrinkage behavior of such concrete was reported as satisfactory.

It could be summarized from the above background literature that MS may have the potential to be used as an alternate material in concrete. However, published work on the physical, mechanical and durability aspects of the resulting concrete is limited and there is a need for more experimental studies for practical purpose. Also, none of the studies suggested the reasons for using MS either as FA or as cement replacements and studies on the durability aspects of concrete containing MS were scarce. Even for concrete containing EAF, which has similar chemical composition, such studies could not be found and the research primarily focused on the mechanical aspects.

Thus the significance of the current work is to study the effect of partial replacements of FA with MS on the physical properties, strength characteristics, basic durability studies and investigations on the microstructure of the concrete containing MS. To achieve this objective, FA will be replaced with MS from 0 to 60 wt% with 10 wt% interval. The effect of the partial replacements on the physical properties, such as, water absorption and density; mechanical properties such as compression, flexural and split tensile strengths of the concrete at 28 days and durability tests will be conducted. Furthermore, the relationships between the mechanical properties of the resultant concrete will also be derived. Micro-characterization of the concrete will be compared to that of the standard sample to relate the property to the microstructure.

III. RESEARCH SIGNIFICANCE AND SCOPE

IV. EXPERIMENTAL SET-UP AND TESTING METHOD

A. Materials:

In this study, Portland Pozzolana Cement, confirming IS 1489-1:2015 [19] was used. Sand confirming zone I with fineness modulus 3.6 and coarse aggregates 20 mm down was used in concrete. Throughout the investigation, tap water was used for mixing and curing. The test for tap water was conducted in accordance to IS: 10500:2012 [20]. The results are presented in Table 1. These parameters are in conformance with the prescribed limits and hence could be satisfactorily used in the investigation.

Table 1 Tap water characteristics confirming IS: 10500:2012 [20]

S No.	Parameter	Value
1	Chloride	150 mg/l
2	pH	7.4
3	Fluoride	0.42 mg/l
4	Dissolved Oxygen	10.23 mg/l
5	Chemical Oxygen Demand	0
6	Biological Oxygen Demand	0
7	Free Residual Chlorine	0.12 mg/l

MS was collected from a private steel rolling industry located in the state of Madhya Pradesh, India with a permission to make use of the material in the current research work. Fig. (1) shows the image of MS used. MS was dried in oven at 90°C for 24 hours. Extensive physical and chemical analysis of the MS sample was conducted to study the basic feasibility of the material for potential use in concrete.

B. Mix Proportioning: Partial replacement of FA using MS was done with successive increments of 10% by weight of up to 60%. For brevity, notation presented in Table 2 is used for mixes containing different percentages of MS. The mix proportions of concrete containing MS was done based on IS: 10262:2009 [21] and are presented in Table 3. A preliminary mix with a water-cement ratio of 0.40 resulted in a stiff mix which was not workable and the slump value was found to be only 25 mm. Hence, in order to make the fresh concrete workable, the water-cement ratio was increased to 0.50.

Figure 1. Sample of MS used in the current work.

C. Test program and test procedure

The fresh state properties were studied using slump test in accordance with IS: 7320-1974 [22]. Physical properties such as water absorption, porosity, dry unit weight, bulk unit weight and sorptivity were measured on 100 mm concrete cubes confirming to IS 1199:1959 [23].

Table 2: Notation of mixes and their expansion

Notation	Expansion of Notation
NAC	Natural Aggregate Concrete
MS10C	Concrete with 10% mill scale by weight of total fine aggregate
MS20C	Concrete with 20% mill scale by weight of total fine aggregate
MS30C	Concrete with 30% mill scale by weight of total fine aggregate
MS40C	Concrete with 40% mill scale by weight of total fine aggregate
MS50C	Concrete with 50% mill scale by weight of total fine aggregate
MS60C	Concrete with 60% mill scale by weight of total fine aggregate

The compressive test was conducted using 150 mm concrete cubes. For the split tensile test, cylindrical specimen measuring 100 mm X 200 mm were prepared. Flexural members were prepared with dimension 100 mm X 100 mm X 500 mm. Ultrasonic pulse velocity (UPV), a non-destructive test was conducted on the 150 mm cube specimen before the conduction of compression test in accordance with IS: 13311 (Part-1): 1992. [24]. the design mix proportion for C20/25 grade concrete used in present work is presented in Table 3.

Table 3: Design mix proportions of C20/25 concrete with varying % replacements of fine aggregate with mill scale.

Mixes	Cement	Fine Aggregate	Coarse Aggregate	Water	Mill Scale
NAC	1	1.9	2.86	0.5	0.00
MS10C	1	1.77	2.86	0.5	0.20
MS20C	1	1.69	2.86	0.5	0.42
MS30C	1	1.55	2.86	0.5	0.66
MS40C	1	1.37	2.86	0.5	0.92
MS50C	1	1.22	2.86	0.5	1.02
MS60C	1	1.05	2.86	0.5	1.14

V. RESULTS AND DISCUSSION

A. Physical and Chemical tests of MS

Extensive physical and chemical analysis of the MS sample was conducted to study the basic feasibility of the material for potential use in concrete. Important physical and chemical properties are tabulated in Table 4.

Table 4. Physical and chemical properties of mill scale.

S.No.	Physical Property	Description
1	Color	Bluish black
2	Specific gravity	4.96
3	Water absorption	< 0.5%
4	Permeability	Moderate
5	SiO_2	8.35 %
6	R_2O_3 (Al_2O_3 + Fe_2O_3)	81.18 %

The particle size distribution of MS and fine aggregate are shown in Fig.1(a). Most of the particle size of MS was < 1 mm with a major quantity of particle in the size range less than 600 µm. Fine aggregates River sand conforming to zone III of IS: 383 [IS:383 (2016)] having fineness modulus of 2.3, specific gravity of 2.6 and water absorption of 2.42 % was used. The sieve curve of the fine aggregate is given in Fig 1 (b). The elemental characterization of mill scale was carried out by Ultima 2 Inductively Coupled Plasma-optical emission spectrometer (ICP-OES). The results are presented in Table 5. Since, the ICP cannot estimate the quantity of oxygen present, the sum total of the mass percentage of all the elements is not 100%. Nevertheless, this chemical analysis provides us with a rough estimate of the constituents of mill scale. Global composition of phases present in MS was identified by XRD measurements using Bruker D8 Advance X-ray diffractometer using powder technique. X-rays were produced using a sealed tube and the wavelength of X-ray was 0.154 nm Cu Kα radiation at 45kV and 40mA and was detected using a fast counting detector based on Silicon strip technology (Bruker LynxEye detector).

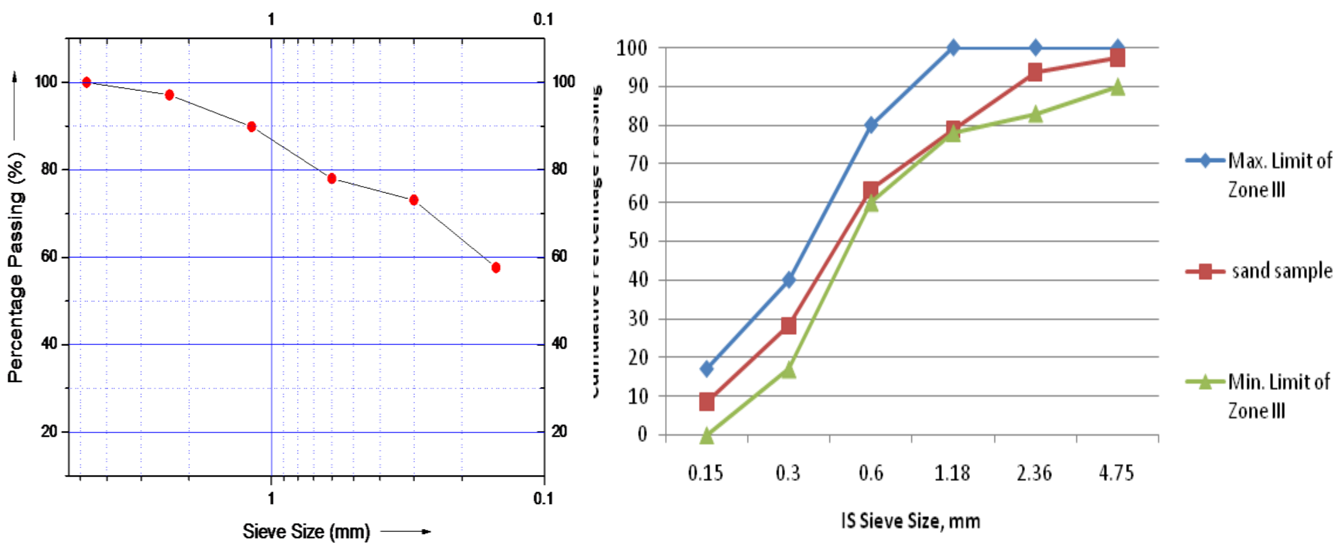

Fig. 1. Particle size distribution of mill scale.

Table 5. Elemental characterization of mill scale using ICP-OES

Element	Fe	Al	Si	Mn	Cr	Ni
Mass (%)	70	2	3.3	0.78	0.43	0.05

The XRD spectrum was acquired from 10º to 90º angle 2θ with a step size of 0.02º. The experimental X-ray pattern of mill scale is shown in Fig.2. The phase identification is done using X'pert HighScore Plus Rietveld Analysis software in combination with Pearson's crystal structure Database. Since no significant peaks were observed after 62º, the results are shown only for this region. The results of XRD analysis consisting of various phases present along with the reliability factors as obtained by Rietveld analysis are tabulated in Table 6.

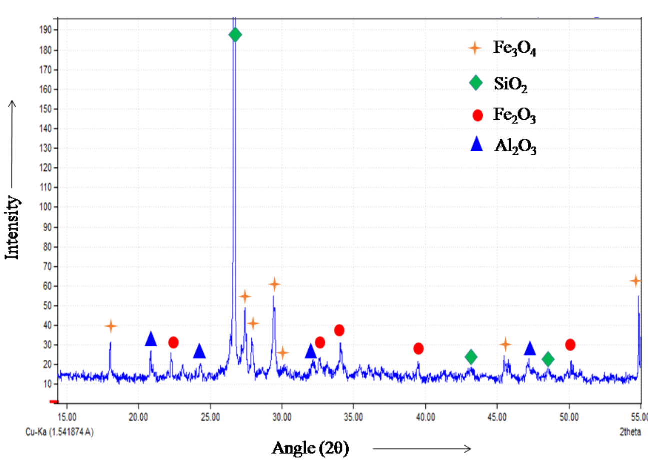

Fig. 2 XRD pattern of Mill Scale.

Table 6 Phases identified in Mill Scale by XRD and Reliability factors.

Phase name	Phase composition	Reliability Factors		
		R_e	R_{wp}	S
Hematite	Fe_2O_3	17.156	21.729	1.604
Magnetite	Fe_3O_4			
Wustite	FeO			
	Al_2O_3			
	SiO_2			

a) Micro-structural characterization of MS

Energy Dispersive Spectroscopy (EDS) coupled with SEM was used to understand the morphology of MS and verify the results obtained from XRD. The phase compositions were studied using Hitachi S-3400N SEM equipped with EDS. The analysis of samples was carried out with a 2 µm probe diameter, 15 kV accelerating voltage and 50 nA probe current. The error of the SEM measurements is estimated to be about ± 2 at.%. Fig. 3 shows the secondary electron (SE) image of MS.

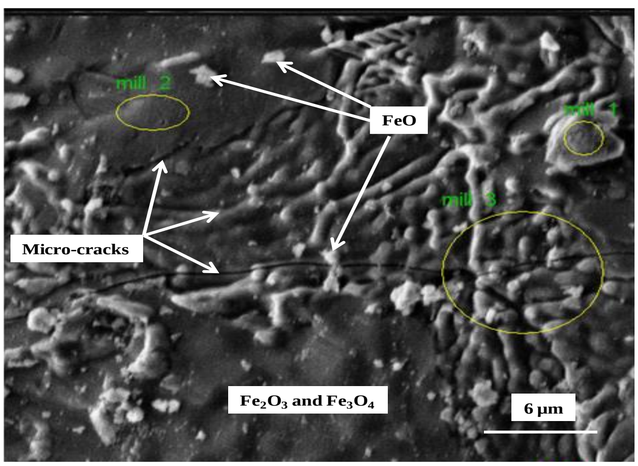

Fig 3. Microstructure of MS

Three regions with distinct morphology were identified for EDS analysis to get the spectral composition. These are marked as mill 1, mill 2 and mill 3 respectively. The phase composition of all the three regions consisted of FeO, CaO and SiO_2. Specifically, the O/Fe ratio in regions 2 and 3 was found to be approximately 1.6, while in region 1, it was 0.98. As also reported by Bagatini et.al. [5], this outer layer of MS majorly consists of oxides of iron, that is Hematite and Magnetite (Fe_2O_3 and Fe_3O_4) in a matrix with globules of FeO dispersed throughout as also shown in Fig.3. The brittleness of this layer in MS is evident from the micro-cracks. In general, the surface of MS is uneven, and hence, it is expected to result in improved binding with cement paste. Similar morphology was also reported by Azad and Kesavan [25].

Based on the physical and chemical analysis of MS, it could be concluded that the smaller particle size, along with the presence of large amounts of crystalline silica (from XRD data) and iron content indicated that MS could be utilized for partial replacement of cement in concrete, while low water absorption, high specific gravity, uneven surface and inert and stable chemical nature of Fe_2O_3 and SiO_2 prompted that MS could be used as a potential substitution of FA. Hence, lime reactivity test was conducted to understand the suitability of MS for partial replacement of cement.

B. Lime reactivity test:

In order to assess the reactivity of MS as a pozzolanic material for use as potential substitute of cement, lime reactivity test was performed in accordance to IS: 1727-1967 [26]. Six cubes of size 50 mm X 50 mm X 50 mm were cast by mixing the ingredients in an electrically driven epicyclic mixer. Dry materials for the test were calculated as per the standard norms as 100 *N*: 400:1500 (MS: cement: sand), where N is the ratio of specific gravity of MS to that of cement. The MS used for mixing was washed and dried in order to remove contaminants. The quantity of mixing water was ascertained by flow table test and found to be 220 ml. After 48 hrs of casting, the cubes were de-moulded and carefully placed in humidizing chamber at 27°C and a relative humidity of 90 for 8 days. The cubes were tested in compression testing machine by applying a uniform compressive force at the rate of 35 Kg/cm^2/min. The average compressive strength for all cubes was found to be less than 2 MPa. The results show that MS used in the current work did not show pozzolanic activity and hence would be more effective as a filler material partially replacing the fine aggregates rather than as a substitute for cement.

C. Workability

Slump test in accordance with IS: 1199-1959 [27], was conducted on fresh concrete to investigate the workability. The fresh mix of concrete containing MS appeared rich and cohesive. The test values of workability are presented in Table 7. The mix was designed for medium slump value in the range 75-100 mm, as per IS: 456-2000 [28]. Fig. 4 shows that the slump values decreases with increasing MS content. For the control mix, the slump value was found to be 85 mm. Addition of MS drastically reduced the slump and at a replacement percentage of 60%, nearly 74% reduction in slump value was observed. These findings are in agreement with those obtained by Singhal et al. [13]. The reduction in slump implies increase in water demand and is an interesting feature of concrete containing MS because; the latter in itself has negligible water absorption (Table 4). This is graphically represented in Fig.1 in terms of percentage of MS vs cumulative water demand.

The increased water demand and hence the reduced slump could be ascribed to irregular shape of particles, which negatively contribute towards the "ball-bearing effect". Also, due to the irregular and flaky surface texture additional cement paste is required around the surface area of MS, which results in stronger MS-matrix bond and hence, reduced slump.

Table 7 Slump of fresh concrete with increasing % replacements of fine aggregates by Mill scale

S.No.	Concrete	Slump (mm)
1	NAC	85
2	MS10C	78
3	MS20C	65
4	MS30C	52
5	MS40C	40
6	MS50C	30
7	MS60C	22

One of the concealed advantages of using MS, on the fresh concrete properties could be reduction in bleeding, which is caused due to increasing water demand. But it should be also noted that increased water demand leads to higher possibilities of plastic shrinkage. Hence, in the mix design of concrete containing MS water workability of the mix and hence the water demand plays a very significant role.

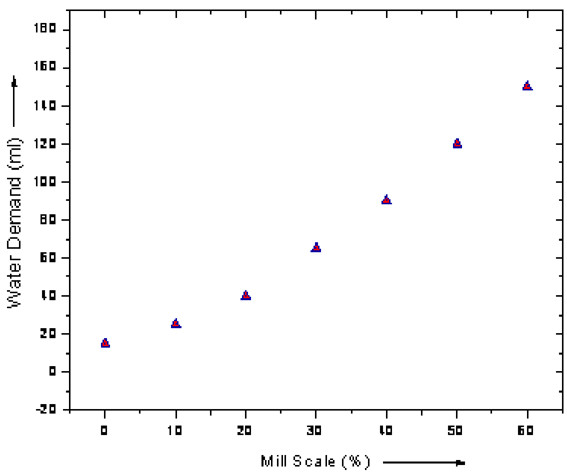

Fig.4. Water demand vs percentage of MS addition.

D. Water Absorption And Porosity

In order to determine the water absorption and porosity, 100 mm concrete cubes were used after curing for 28 days. The surface dried weight (W_{sat}) was determined accurately to three decimal places. These samples were oven dried at 105°C for 24 hrs and the dry weight (W_{dry}) was recorded. Later, they were immersed again in tap water for 24 hrs, the surface was dried and the weight of the cubes were recorded (W_{wat}). The following equations were then used to determine the water absorption, volume of voids and porosity:

$$\text{Water Absorption (\%)} = (W_{sat}-W_{dry})/W_{dry}\,X100 \quad (1)$$

$$\text{Porosity} = (W_{sat}-W_{dry})/(W_{sat}-W_{wat})\,X\,100 \quad (2)$$

These equations for calculating the water absorption and porosity have been reported by various authors [29-32]. The results given in Table 8 indicate that as the amount of MS in concrete increases, water absorption, volume of voids and porosity decreases. The decreasing trend of these properties is attributed to the fine particle size of MS and also to the very low water absorption characteristics, as shown in Table 4. The fine particles tend to fill the smaller voids in concrete thereby decreasing the water absorption and porosity. Further, the decreasing values of water absorption and porosity indirectly indicate good bond of MS particles with hydration products of cement, which tends to decrease the porosity and hence the water absorption.

E. Unit Weight of concrete

The variation of bulk and dry unit weight of concrete with increasing percentage of MS is shown in Fig.5. As expected, compared to NAC, the unit weights of all concrete containing MS is higher. Also, due to reduced porosity of the resulting concrete and the higher specific gravity of MS, the unit weights of concrete shows an increase with the increase in MS content. Further, it is observed that this increment is more in MS10C to MS40C. For MS50C the unit weight is maximum, after which there is a slight drop in the values.

Table 8 Physical Properties of concrete containing MS

Mill Scale	Water Absorption	Porosity
NAC	5.430	7.215
MS10C	5.380	7.109
MS20C	5.210	6.735
MS30C	5.090	6.616
MS40C	4.950	6.425
MS50C	4.880	6.337
MS60C	4.750	6.206

This is because up to MS50C, the MS aids in filling up the voids to increase the density, after which MS contributes as fine aggregate as the voids are saturated with MS.

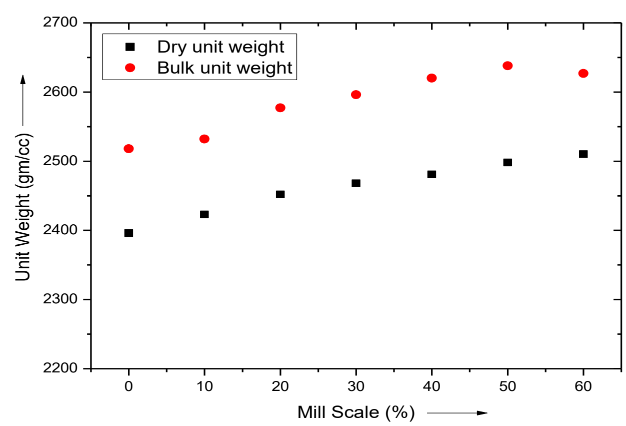

Fig.5. Variation of unit weights vs MS content

F. Mechanical Properties

Table 9 shows the 28 day compressive, split tensile and flexural strength results of control mix and concrete containing MS. A total of 140 samples of cubes with various percentages of replacements were casted for testing the compressive strength characteristics of concrete in accordance with IS: 516 (1959) [33]. The results show that the cube compressive results decrease as the MS content in concrete increase. The addition of 10%, 20%, 30%, 40%, 50% and 60% weight fractions of MS decreased the compressive strength by 3.8%, 11.4%, 13.8%, 17.7%, 31% and 34.5% respectively with respect to control mix.

The split tensile strength and flexural strength also show a decreasing trend with increase in MS content. For example, at 60% replacement, the split tensile strength shows nearly 19% decrease while flexural strength shows 27% decrease in strength compared to control mix. It could be seen that although the addition of MS, in general, decreases the strength characteristics of concrete,

Table 9 Mechanical Properties of Concrete containing MS after 28 days of curing

S.No.	Mixes	Compressive Strength (MPa)	Split Tensile Strength (MPa)	Flexural Strength (MPa)
1	NAC	29	3.29	6.12
2	MS10C	27.9	3.21	5.79
3	MS20C	25.7	3.12	5.47
4	MS30C	25	3.05	5.35
5	MS40C	24	2.96	5.19
6	MS50C	20	2.66	4.74
7	MS60C	19	2.63	4.37

yet additions up to nearly 40% does not how significant reductions (17.7%). Thus, replacements up to 40% by weight of fine aggregate in concrete can be considered without much reduction in strength.

VI. MICROSTRUCTURE CHARACTERIZATION OF CONCRETE

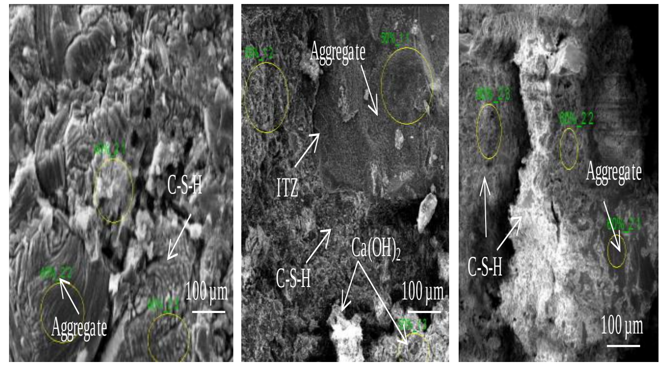

Fig.9. Microstructure of concrete containing MS upto (a) 40%, (b) 50% and (c) 60%.

In order to understand the results obtained from the mechanical testing of concrete containing MS, microstructural analysis of the concrete was also performed on concrete samples MS40C, MS50C and MS60C. The SEM-SE images of the samples are presented in Fig.9 (a-c) at 100 µm. EDS analysis for these samples were also done to identify the various phases present. Fig 9 (a) represents the SE image of concrete containing MS40C. It is evident that the micro-structure is homogeneous, containing significant C-S-H gel and a strong interfacial transition zone (ITZ). The spectrum analysis revealed the presence of 36.53 at %. of elemental Fe indicating presence of MS. Similar results were found in MS50C and MS60C as well. This implies that MS does not interact with the products of hydration and thus no new phases are formed indicating its inert nature. The SE images of MS50C is presented in Fig. 9 (b) and shows a more coherent C-S-H gel indicating stronger bond with aggregates at 50% replacement. This is supported by the fact that the dry unit weight and bulk unit weight are maxima for MS50C. As the replacement percentage increases to 60% (Fig. 9 (c)) wide cracks are predominant. This possibly results in a reduction in unit weight values (Fig. 5). Further, the formation of cracks is possibly due to high water demand of the fresh concrete of MS60C, which could yield shrinkage cracks in concrete. This study enabled to understand the correlation of microstructure with the water demand, unit weights and strength characteristics of the concrete. It also confirmed the inertness of MS towards the products of hydration.

VII. CONCLUSION

Experimental investigations to study the effect of partial replacement of FA with MS are attempted in this research work. The physical and chemical properties of MS and its viability to be used as replacement of FA through lime reactivity test were carried out. A systematic study on the fresh and hardened properties of concrete by the partial addition of MS as fine aggregate was undertaken. The utilization of MS in concrete is done with an objective to provide a channel for effective consumption of a metal industry waste produced in huge quantities and posing grave environmental hazards thereby producing green concrete. It could be safely concluded that MS does not possess pozzolanic activity and is hence not suitable for replacement of cement. MS in concrete acts only as a filler material. The mechanical properties such as compressive strength, flexural strength and split tensile strength of the concrete containing MS decrease with increasing replacements, although, replacement up to 40% did not result in drastic reductions of strength of concrete. Additional tests on chemical effects on resulting concrete and durability aspects such as freeze and thaw, abrasion resistance, rapid chloride penetration test etc. could be conducted to further ensure the quality of resulting concrete.

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CONFLICT OF INTEREST

The author declares that there is no conflict of interest.

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