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Characterisation of Iron Ore Tailings as Fine Aggregates for Mortar and Concrete

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ABSTRACT

Construction industry consumes bulk volume of natural resources. Fine aggregate is one such essential ingredient for construction materials such as concrete, mortar, masonry units etc. The properties of mortar and concrete largely depend on the quality of fine aggregate used. Natural river sand is widely used as fine aggregate. However, river sand is becoming a scarce commodity and there is ban on mining of sand due to environmental concerns. Hence, attempts are being made for exploring suitable alternatives to river sand. In the present investigation suitability of iron ore tailings (IOT) as an alternative to river sand for fine aggregate is examined. As part of this study, extensive experimental investigations were conducted for characterisation of properties of IOT, determination of properties of mortars and concrete using IOT as fine aggregate. The results on physical and chemical properties of IOT are discussed and few basic properties of mortar and concrete having IOT as fine aggregate are presented. The results reveal that IOT samples are fine grained (fineness modulus of about 0.2). A blend of IOT and natural river sand improves the grain size distribution leading to considerable improvement in the workability and strength characteristics of the mortar and the concrete. It is found that IOT can replace up to about 75% river sand in mortars and 50% in concrete.

Keywords: Mine waste, Iron-ore tailings, Fine aggregate, Concrete, Mortar, Masonry

1 INTRODUCTION

The construction industry caters to the demand for new buildings and other infrastructure projects. Natural river sand, which is an essential construction material, has become a scarce commodity in many parts of the world. Un-controlled mining of river sand is damaging ecology and affecting environment. Hence, there is a strong opposition from environmentalists on sand mining and it is even banned in many river basins in India. Because of this, sand is being hauled from considerably long distances at the expense of transportation energy (Reddy & Jagadish, 2003). This has direct impact on the cost of construction projects and sustainability of construction industry. This is a serious issue in many parts of the globe and hence, considerable research efforts are being made for exploring alternative materials to natural river sand. On the other hand, considerable volumes of non-organic solid wastes are being generated by various industrial and mining activities. Accumulation of these wastes also has serious environmental consequences in terms of safe storage and disposal. Utilization of non-organic solid wastes such as fly ash, slag, mine tailings, construction and demolition waste (CDW), granite cutting waste (GCW), polished porcelain tile waste etc., as raw materials for construction activities is an interesting area of research pursued across the globe (Gorai et al., 2003; Kumar et al., 2006; Ahmaruzzaman, 2010; Kinuthia & Nidzam, 2011; Rodrigues et al., 2013; Ke et al., 2016; Venkatarama Reddy et al., 2016; Singh et al., 2016). Waste utilisation not only addresses safe disposal and management of wastes but will also reduce utilization of natural mined materials for infrastructure construction. This supports sustainable growth of construction industry as efficient utilisation of energy, resources and materials are considered as key components for sustainable design practice (Iwaro & Mwasha, 2013). A research (Pappu et al. 2007) estimated the volume of different solid wastes generated in India and discussed possible opportunities for their utilisation of in construction industry. It is estimated that about 290 million tonnes of non-organic solid wastes are being generated per year in India, out of which 11 million tonnes is iron ore tailings (IOT). Various researchers have examined utilization of iron ore tailings as raw material to make value added construction products. The main focus of these studies was on further beneficiation possibilities and utilization of silica present in tailings as raw material in ceramic industry (Ghosh & Sen, 1999; Das et al., 2000). Also, attempts have been made to utilize IOT in fertilizer production, cement manufacturing, pre-cast construction products and other value-added products (Zhang et al., 2006 and Zhong-lai et al., 2009). In all these applications IOT must be processed which is energy intensive.

2. OBJECTIVES AND SCOPE OF THE INVESTIGATION

The objectives of the study presented in this paper is to determine the physical and chemical properties of IOT and to examine its suitability as fine aggregate in mortar and concrete. The physical characteristics investigated include grain size distribution, density, percentage voids and specific gravity of IOT sample. Few of the IOT samples were analysed for their chemical composition. The shape and surface topography of the particles of IOT were determined using scanning electron microscope (SEM). The characteristics like workability and compressive strength of mortar and concrete having IOT as fine aggregate (partial or full replacement to river sand) are also examined.

3. SAMPLING METHODS ADOPTED TO EXTRACT IOT

The Lakya dam (at Kuduremukh, Karnataka state, India) was built to store the iron ore tailings generated during about three decades of mining and ore extraction process. The dam is located at a Latitude 13^0 14' 56" N and Longitude 75^0 13' 30" E. The IOT stored in the dam has spread across an area of about 2 square kilometres for a depth of about 100 m. About 200 million tonnes of IOT has been stored in this dam (Venkatarama Reddy, 2009). The IOT samples were collected from six different locations at 1.0 m depth from top surface across the dam coverage area. The IOT collected from these locations are designated as L1, L2, L3, L4, L5 and L6 (shown in Figure 1). It should be noted that the tailings were discharged into the storage dam in the form of flowing slurry and hence the IOT particles settle down exposing water which drains out at farthest end from IOT discharge point. As IOT is discharged in slurry form, it is expected that the heavier particles settle at faster rate when compared to the fine particles. This kind of discharge can result in variations in the grain size distribution of IOT sampled across the storage area as well as across the depth of the storage in the dam. Hence, to verify this, the samples were collected from three bore holes (BH1, BH2 and BH3) up to a depth 6m (shown in Figure 1). The IOT material was extracted at different depths (Table 2) using manual operated helical auger.The location L5 was close to the service road and hence about 20 metric tonnes of IOT from this location was collected in plastic bags and stored in a covered masonry tank in the laboratory and used in most of the experiments on mortars, masonry and concrete.

4. PHYSICAL PROPERTIES OF IOT SAMPLES

4.1 Grain size analysis

One of the basic physical parameters of concern in assessing the suitability of fine aggregate for mortar and concrete applications is the grain size distribution. Grain size analysis of the tailings was carried out following the guidelines of Bureau of Indian Standard (IS: 2386 (part I), 1963). Particles finer than 75 µm were further analysed through hydrometer analysis. The grain size distribution curves for the river sand and the IOT collected at a depth of 1.0 m from the top surface at locations L1 to L6 are shown in Figure 2. Similarly, the grain size distribution curves were obtained for the IOT collected from the three borehole locations BH1, BH2 and BH3.

4.2 Fineness modulus, Specific gravity, Bulk density

The specific gravity and the percentage of voids are important parameters for fine aggregate in designing the mix proportions of concrete. In masonry mortars, the bulk density of fine aggregate in loose state was used in converting volume mix proportions to weight ratios. The BIS code (IS: 2386 (Part III), 1963) and the American Standard code (ASTM: C 29/C 29M, 2009) give procedure to determine specific gravity and bulk density based on which percentage voids in aggregate is determined. The percentage voids give an idea of the particle packing in the aggregate matrix. The results obtained on samples collected from six locations are presented in the Table 1. The natural river sand used to produce the control mortar and the concrete mix had a fineness modulus of 2.71 and specific gravity of 2.57. Similar physical properties were determined for the IOT samples collected from three borehole locations (BH1, BH2 and BH3) and the test results are presented in Table 2. The SEM analysis was carried out to find out the shape of the IOT particles collected from the six locations. A typical SEM image is shown in the Figure 3.

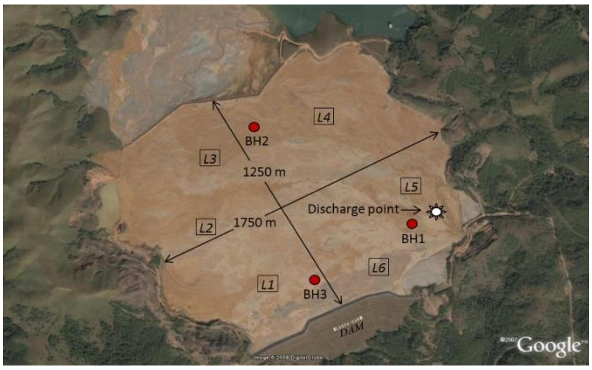

Figure 1. *Top view of Lakya dam showing storage of iron ore tailings with sampling locations*

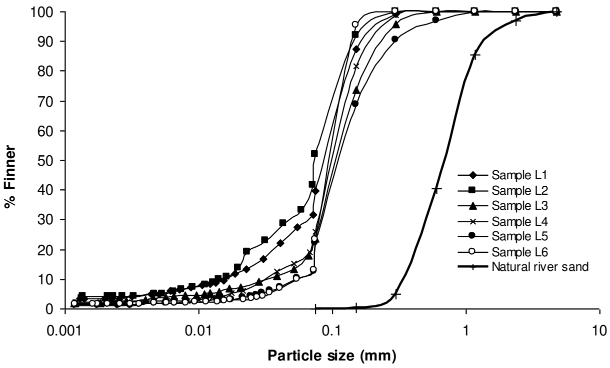

Figure 2. *Grain size distribution curves of natural river sand and IOT samples at locations L1 to L6 at a depth of 1m from the surface*

4.3 Fineness modulus, Specific gravity, Bulk density

The specific gravity and the percentage of voids are important parameters for fine aggregate in designing the mix proportions of concrete. In mortars, the bulk density of fine aggregate in loose state was used in converting volume mix proportions to weight ratios. The BIS code (IS: 2386 (Part III), 1963) and the American Standard code (ASTM: C 29/C 29M, 2009) give procedure to determine specific gravity and bulk density based on which percentage voids in aggregate is determined. The percentage voids give an idea of the particle packing in the aggregate matrix. The results obtained on samples collected from six locations are presented in the Table 1. The natural river sand used to produce the control mortar and the concrete mix had a fineness modulus of 2.71 and specific gravity of 2.57. Similar physical properties were determined for the IOT samples collected from three borehole locations BH1, BH2 and BH3 and the test results are presented in Table 2. The SEM analysis was carried out to find the shape of the IOT particles collected from the six locations. A typical SEM image is shown in the Figure 3.

Table 1. *Physical properties of IOT samples from six locations at 1 m depth.*

Location	Sand size fraction 4.75-0.075 mm (%)	Silt size fraction 0.075-0.002 mm (%)	Clay Size fraction < 0.002 mm (%)	Fineness modulus	Specific gravity	Bulk density in loose state (kg/m^3)	Voids in loose state (%)
L1	60.20	36.20	3.60	0.13	2.96	1330	55.06
L2	48.20	47.70	4.10	0.08	2.77	1280	53.57
L3	76.20	21.80	2.00	0.30	3.35	1280	61.79
L4	79.40	23.60	2.20	0.19	3.32	1320	60.07
L5	75.00	20.70	1.30	0.43	2.77	1300	53.10
L6	76.80	21.70	1.50	0.06	2.77	1280	53.57

5. CHEMICAL ANALYSIS OF IOT SAMPLES

The characteristics of concrete and the mortar largely depend on the quality and the quantity of hydration products developed during the hydration of cement and on the density achieved. Hence, it is important to use constituents of concrete and mortar which are free from any undesirable elements. Hence, the tailings samples were analysed for the chemical composition. Initially the EDX analysis was carried out to identify the major elements present in the tailings. Based on the chemical analysis reported in earlier studies on utilization of IOT (Ghosh & Sen, 1999; Das et al., 2000; Zhang et al., 2006 and Zhong-lai et al., 2009), two samples were analysed for similar radicals, total dissolved salts (TDS) and the results are presented in the Table 3. The pH of the aggregate is another factor which can interfere in the hydration process of cement and hence pH value of IOT was also determined.

6. TESTS ON MORTAR AND CONCRETE

6.1 Workability and compressive strength of mortar

Among the three grades of mortars examined for various parameters in the overall study, the experimental results of workability and compressive strength tests for M2 grade cement-sand mortar (1 cement: 6 sand, by volume) conforming to BIS code (IS: 1905, 1987) is only discussed in this paper. The mortar having natural river sand as fine aggregate was chosen as control mortar (named as M2A). The mortar mix having 100% IOT as fine aggregate is designated as M2D. Two more mortar mixes were examined in which the fine aggregate was a mixture of natural river sand and IOT (reconstituted fine aggregate). The reconstituted fine aggregate having 75% natural river sand and 25% IOT was designated as RSC1 and 50% natural river sand and 50% IOT was designated as RSC2. The mortar mixes having RSC1 and RSC2 as fine aggregate have been designated as M2B and M2C respectively. Grain size distribution curves of RCS1 and RCS2 are shown in Figure 4 along with the upper and the lower bound curves of the fine aggregates to be used in mortars and concrete as per BIS codes (IS: 2116, 1980) and (IS: 383, 1970). The rodded bulk density and void content of the river sand, IOT from location L5 and the reconstituted sands were determined as per the American Standard code (ASTM: C 29/C 29M, 2009) and the results are reported in Table 4.

Workability of the four mortars was determined by flow test method as per the British Standard code (BS: 4551, 1980). From the earlier study on mortar characteristics, it was found that desirable workability for mortars is in the range of 80-100% (Venkatarama Reddy, 2005 & Ullas, 2008) and hence the workability required was fixed at 85% flow value. The water content required to achieve this flow was determined for all the four mix proportions. Compressive strength of these mortars was determined using 50 mm cubes following the guidelines of BIS code (IS: 2250, 1981). The mortar mix proportions, the water-cement ratio and the strength values are reported in Table 5.

Table 2. *Physical properties of IOT samples from three borehole locations (BH1, BH2 and BH3) at different depths from top surface.*

Location (Depth below top surface)	**Sand size fraction 4.75 - 0.075 mm (%)**	**Silt size fraction 0.075-0.002 mm (%)**	**Clay size fraction < 0.002 mm (%)**	**Fineness modulus**
		Core samples from borehole BH1		
1 to 1.5m	82.80	15.74	1.46	1.44
2.5 to 3m	81.80	16.81	1.39	1.61
4 to 4.5m	87.80	11.10	1.10	1.84
5.5 to 6m	88.00	10.79	1.21	1.86
		Core samples from borehole BH2		
1 to 1.5m	41.80	51.58	6.62	0.12
2.5 to 3m	48.80	46.65	4.55	0.14
4 to 4.5m	39.60	54.28	6.12	0.10
5.5 to 6m	49.80	45.22	4.98	0.16
		Core samples from borehole BH3		
1 to 1.5m	65.20	31.41	3.39	0.26
2.5 to 3m	48.40	47.30	4.29	0.15
4 to 4.5m	59.00	37.53	3.47	0.24
5.5 to 6m	59.20	36.96	3.84	0.27

6.2 Workability and compressive strength of concrete

Two grades of concrete were examined for various properties (strength, shrinkage, durability etc.) in the overall study. The workability and compressive strength test results for M20 grade concrete having 20 MPa characteristic compressive strength is discussed in this paper. The mix design for the concrete was done as per the American Standard code (ACI: 211.1,1991) and the mix proportions are 1: 2.95 : 3.65 by weight (cement : fine aggregate : coarse aggregate). The natural river sand was used as fine aggregate in the control concrete mix and was named as M20A. The concrete mix having 100% IOT as fine aggregate is designated as M20D. Two more concrete mixes were examined in which the fine aggregate was reconstituted fine aggregate RSC1 and RSC2 designated as M20B and M20C respectively. Required workability of the concrete was fixed between 25 to 100 mm slump values as per the BIS code (IS: 456, 2000). The IOT was found to be fine graded in nature and generally, the increase in fines content is expected to demand higher water-cement ratio for required workability. Hence, the water cement ratio was initially kept at the upper limit of 0.66 as per American Standard code (ACI: 211.1,1991). It was found that achieving required workability was not possible beyond 25% natural river sand replacement with the IOT at this water-cement ratio. Hence, the water-cement ratio was subsequently increased till the required workability was achieved and corresponding compressive strength of various trial mixes was determined. Compressive strength of the concrete samples was determined using 150 mm cubes cast, cured, and tested as per BIS code (IS: 516, 1959) guidelines. The concrete mix proportions, water-cement ratio and compressive strength values are reported in the Table 6.

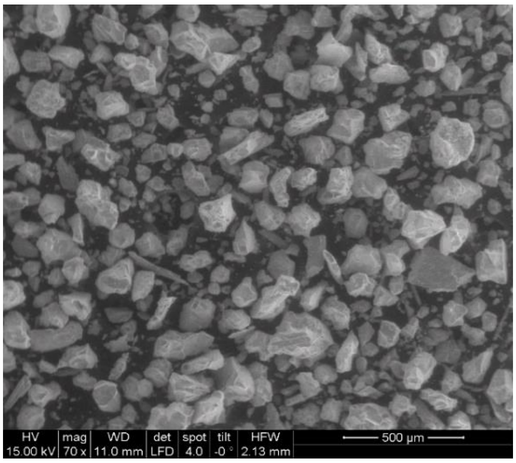

Figure 3. *SEM image of IOT*

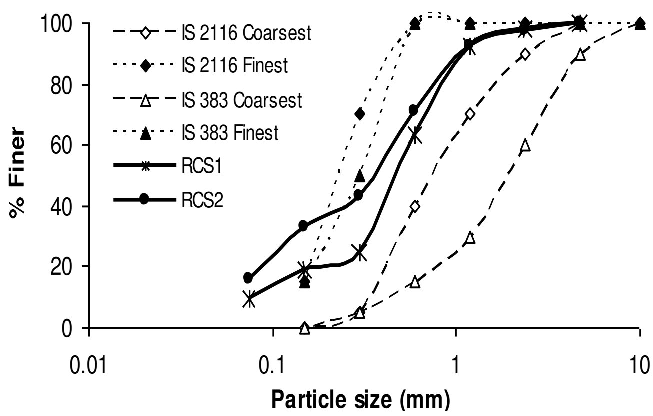

Figure 4. *The grainsize distribution curves of reconstituted fine aggregate samples*

Table 3. *Chemical properties of tailings*

IOT samples	Radicals (%)										
	SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	Na_2O	K_2O	TiO_2	MnO	TDS	pH
L2	60.9	27.4	1.88	1.71	1.79	0.16	0.16	0.22	0.18	228 ppm	8.12
L5	65.9	26.8	1.08	1.59	1.42	0.10	0.07	0.19	0.13	134 ppm	8.16

Table 4. *Physical properties of the natural river sand, IOT (L5 location) and the reconstituted fine aggregate samples.*

Fine aggregate type	Sand replaced (%)	Fineness modulus	Specific gravity	Bulk density (kN/m^3)	Voids (%)
River sand	0	2.71	2.57	1591	38.16
RCS1	25	2.02	2.64	1849	29.82
RCS2	50	1.63	2.70	1903	29.37
IOT (L5)	100	0.43	2.77	1707	38.26

7. RESULTS AND DISCUSSION

7.1 Physical and chemical characteristics of IOT

7.1.1 Grain size distribution of IOT samples at locations L1 o L6 and natural river sand

The IOT from location L2 is the finest among the six samples having both sand and silt size fraction of about 48% and clay size fraction of about 4%. Other IOT samples have sand size fraction between 60 to 79%, silt size fraction between 20 to 36% and clay size fraction between 1.3 to 3.6%. The grain size distribution curves and the fineness modulus values of IOT samples, indicate that IOT samples are very fine grained having an average fineness modulus of 0.2, whereas the natural river sand has a fineness modulus of 2.71. The maximum allowable fraction finer than 0.3 mm as per (IS: 2116, 1980) code is 70% whereas the average value of this fraction in IOT samples is about 95%. Also, the gradation curves of these samples are outside the limiting gradation curves specified in IS 383 for finest sand (Zone IV).

Table 5. *Details of mortar mix proportions and test results*

Mortar designation	Mix proportion (by volume)			Sand replaced (%)	Flow (%)	Water-cement ratio	Compressive strength (MPa)
	Cement	IOT	natural river sand				
M2A	1	0	6	0	85	1.72	4.03 (0.50)
M2B	1	1.5	4.5	25	85	1.52	6.17 (0.65)
M2C	1	3	3	50	85	1.57	5.75 (0.24)
M2D	1	6	0	100	85	2.10	3.32 (0.15)

Standard deviation values in parenthesis

Table 6. *Details of concrete mix proportions and test results*

Concrete designation	Mix proportion (by weight)				Sand replaced (%)	Slump (mm)	Water-cement ratio	Compressive strength (MPa)
	Cement	Fine aggregate		Coarse aggregate				
		IOT	Natural river sand					
M20A	1	0	2.95	3.65	0	65	0.66	31.00 (1.01)
M20B	1	0.74	2.21	3.65	25	80	0.66	37.80 (1.31)
M20C	1	1.475	1.475	3.65	50	70	0.80	30.40 (2.44)
M20D	1	2.95	0	3.65	100	70	1.075	13.81 (0.78)

Standard deviation values in parenthesis

7.1.2 Grain size distribution of IOT samples from the boreholes

The sand, silt and clay size fractions, and fineness modulus values of samples from boreholes are given in Table 2. From the results presented in Table 2, it is found that the IOT at BH1 is coarser compared to the IOT from other two boreholes. This is because the BH1 is very close to the point where IOT was discharged in slurry form. In such a state, the coarser particles settle faster and remain closer to the discharge point. The gradation of IOT around this location falls within the allowable limits given in different codes of practice. Only particles finer than 0.15 mm were about 30% as against 15% and 25% of maximum allowable limits as per Indian and British codes respectively. The IOT samples collected at various depths of BH1 can be classified as Zone IV sand of IS 383 specifications. The IOT sampled at BH1 location has higher average fineness modulus(FM) value of 1.68 compared to the particles at BH2 (FM of 0.14) and BH3 (FM of 0.25) which are farther away from the discharge point. The IOT at BH2 is the finest among three borehole locations as this is the farthest location from the discharge point. The grain size distribution curves of IOT at BH3 fall in between the distributions at BH1 and BH2. Also, it was observed that the gradation of IOT sampled at borehole BH1 becomes progressively coarser along the depth from 1.0 m to 6.0 m with increase in FM value of 1.44 to 1.86

whereas the increase in FM values at other two borehole locations is marginal and not progressively increasing with depth. The values presented in Table 1 and Table 2 represent mean of three samples.

7.1.3 Grain size distribution of reconstituted fine aggregate with IOT

The grain size distribution curves of reconstituted fine aggregate along with IS code specified upper and lower limits on grain size distribution curves are shown in Figure 4. For the fractions >0.15 mm, it can be observed that the gradation of reconstituted fine aggregate RCS1 (25% replacement of natural river sand by IOT) and RCS2 (50% replacement of natural river sand by IOT) lie within the upper and lower bound limits of particle sizes given by IS codes. Only the percentage of particles finer than 0.15 mm is more than the allowable limit. The IS codes allow 15% of particles finer than 0.15 mm whereas RCS1 and RCS2 have 19% and 32.8% of particles finer than 0.15 mm respectively. From the physical properties presented in Table 4, it is evident that as natural river sand is replaced by IOT the specific gravity values increase. The bulk density of reconstituted fine aggregate is more when compared to the bulk density of natural river sand or IOT alone. The voids percentage of natural river sand considerably reduces from 38% to 30% in reconstituted fine aggregate indicating improvement in grain size distribution and particle packing. The fineness modulus of natural river sand (2.71) reduces as IOT content increases in the reconstituted aggregate RCS1 (2.02) and RCS2 (1.63).

7.1.4 Other physical and chemical properties

The average specific gravity of IOT sampled from L1 to L6 locations was found to be 2.99 which is higher than the specific gravity of sand (2.57). This can be attributed to high specific gravity of parent iron ore and the presence of about 27% of residual iron in the samples. The average bulk density in loose state and the corresponding percentage voids of IOT samples is 1300 kg/m^3 and 56.2 % respectively whereas natural river sand has bulk density of 1474 kg/m^3 in loose state and 45.6% voids. It should be noted that the values of bulk density and percentage voids discussed above are at loose state, used in converting volume proportions of mortar to corresponding weight proportions and these values are different from the values presented in Table 4, which are calculated under rodded condition as per ASTM code specification. The density at rodded condition simulates the particle packing of mortar and concrete under specific amount of compaction and hence, used in understanding particle packing through percentage voids. Since the IOT is very fine graded, despite having higher specific gravity the voids content is high and hence lesser bulk density compared to the natural river sand.

The shape of the IOT particle can be seen in the typical SEM image given in Figure 3, where it can be observed that the IOT particles have blunt edges and are not flaky. From the typical analysis results of two IOT samples presented in Table 3, it can be observed that the IOT is predominantly siliceous in nature. The IOT samples are composed of two major elements such as SiO_2 (63%) and Fe_2O_3 (27%). The pH value (~ 8) reveals that IOT samples are slightly alkaline.

7.2 Characteristics of mortar and concrete using IOT as fine aggregate

7.2.1 Workability of mortar and concrete

The mortars and concrete are expected to be workable in green state without demanding too much water which may lead to segregation and bleeding. Though the grain size distribution of the IOT samples differ from the various code's specifications, the codes allow deviation in the stipulated limits, provided the final product such as mortar or concrete performs satisfactorily with respect to the other parameters of concern such as strength, durability, shrinkage etc.

From the workability test results, it was observed that the workability is more at lower IOT replacement of 25% for any given water-cement ratio as compared to the control mix in both the mortar and the concrete. From the data presented in Table 5, it can be seen that the water-cement ratio reduces from 1.72 to 1.52 in order to achieve required mortar flow value of 85% when 25% of natural river sand is replaced by the IOT. Similarly, in the case of concrete, the increase in slump value (65 mm to 80 mm) was observed at similar water-cement ratio of 0.66. This can be attributed to the fact that the fine grained IOT particles improve the gradation of river sand at low replacement levels. The results presented in Table 4 support this argument by clearly indicating reduction of voids percentage (38.16% to 29.37%) in reconstituted fine aggregate with up to 50% IOT replacement compared to the natural river sand and the IOT alone. Because of the improved gradation of the river sand-IOT mixture (at 25% replacement of natural river sand by IOT), better workability was obtained for both the mortar and the concrete.

7.2.2 Compressive strength of mortar and concrete

The important parameter of concern with mortar and concrete is to achieve required compressive strength with the IOT as fine aggregate. The compressive strength results of mortar and concrete as sand was replaced by IOT are given in Table 5 and 6 respectively (the strength values given in these Tables represent the mean of four samples). It can be observed from these results that the compressive strength of both the mortar and the concrete increase as 25% of sand was replaced by IOT 25%. The improved workability and the strength of the mortar and the concrete at 25% sand replacing IOT was due to reduced water content and reduced voids percentage. When 100% IOT was used as fine aggregate, water demand increases to obtain required workability, voids percentage also increases, and hence compressive strength of mortar and concrete decreases.

The required workability of mortar was set at 85% flow value and specimens were cast with the water-cement ratio corresponding to this required workability. In the case of mortar, the compressive strength increased to 6.17 MPa from 4.03 MPa when 25% of river sand was replaced by IOT. The compressive strength reduced from 4.03 MPa to 3.32 MPa when 100% IOT was replacing the natural sand. However, the relationship between the strength and IOT replacement level reveals that the mortar compressive strength is slightly more than that of the control mortar strength at 75% sand replaced with IOT.

The required workability of concrete was set at 25 - 100 mm slump and corresponding water-cement ratio of control concrete was 0.66. Considerable increase in compressive strength was observed when 25% natural sand was replaced by IOT. The concrete compressive strength at 50% sand replacement with IOT is comparable to that of control concrete. At higher IOT contents, the water-cement ratio is more to achieve required workability and it was not possible to obtain required slump value for water-cement ratio less than that reported in Table 6. The increase in water-cement ratio results in considerable reduction in compressive strength from 31.00 MPa to 13.81 MPa when 100% natural sand was replaced by IOT. Improvement in workability and compressive strength of concrete at initial replacement of sand with IOT is in good agreement with the literature (Singh et al., 2016) where granite cutting waste, which is finer material like IOT, was used for replacing the river sand in concrete.

8. CONCLUDING REMARKS

Partial replacement of natural river sand by the IOT reduces the voids content and improves the overall gradation of the reconstituted fine aggregate. The reconstituted fine aggregate nearly conform to the desirable limits of particle size specifications. Partial replacement (25%) of sand by IOT leads to better workability and improvement in compressive strength for both mortar and the concrete. When 100% IOT is used as fine aggregate, water demand increases to achieve the required workability and hence compressive strength of mortar nominally decreases whereas the concrete strength decreases considerably.

9. ACKNOWLEDGEMENTS

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