A study on suitability of iron ore overburden waste rock for partial replacement of coarse aggregates in concrete pavements

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Abstract. Concrete is the most widely used construction material, several sustainable materials are under investigation to reduce the impact of its production processes, by considering partial replacement of natural constituents with the waste materials without compromising the durability and strength of concrete in view to reduce both the demand of raw material and effective waste disposal of millions of tons from different sources. There has been a constant research to substitute the natural aggregates with other waste materials to develop sustainable pavements. In the process, the waste produced from Mining industry is one of such source. The aim of this study is to evaluate the suitability of iron ore waste as partial replacement of coarse aggregates in concrete with reference to the conventional materials. Physico-chemical properties and aggregate tests such as crushing, abrasion, impact, shape test, the specific gravity and water absorption were determined as per Standards and the results were within the limits indicating their applicability as a pavement material. Partial replacement by 20%, 40%, 60%, 80% and 100% with waste rock was tested for its mechanical properties and it was found that, 40% replacement of waste rock yielded highest compressive strength compared to the control mix. Regression analysis was carried out to predict the performance analysis of the compressive strength of the samples with IOT.The performance prediction analysis shows that curing days influencing more compared to % replacement with IOT.

1. Introduction

Over the period of time the amount and type of waste material generated increased accordingly. Many of the non-decaying waste materials will remain in the environment for hundreds or perhaps thousands of years. The non-decaying waste materials cause a waste disposal crisis, thereby contributing to the environmental problems. Mining Industry is one source of availability of a large quantity of waste material after agriculture in nation development. Waste from mining includes overburden waste, tailings, dumps, and other processed waste. There are two methods of mining, one is open-cast and the other is underground mining. Open-cast mining involves removal of complete waste rock to expose the ore body or coal. One of the common environmental problems associated with these tailings is the formation of acid mine drainage which can be a potential source of surface and ground water pollution [1]. These tailings also consume a lot of land that could be used for other purposes, and compromise the good looks of the environment in these areas [7], [9]. There can be a potential of erosion from these tailings dumps into the environment [10]. Utilization of such waste rock is being investigated by various researchers for different purposes such as in construction materials, pavements, back filling

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etc. Hence, a partial replacement of the aggregates in concrete by waste rock produced from mines is not only economic in the handling and maintenance of waste dumps but also reduces the cost of construction of roads. In addition, it also reduces the environmental problems at mine site. The feasibility of utilization of steel slag as aggregate in stone mastic asphalt (SMA) mixtures was investigated [8]. Sand is replaced partially with laterite and sandstone respectively, there was not much improvement on strength properties of concrete yet these can be used as a replacement for sand [5], [6]. Iron ore tailings were used as replacement of fine and coarse aggregate and it was found that it is suitable as a construction material [2].

2. Experimental Program

To assess the suitability of iron ore overburden waste rock (OB-WR) as replacement of coarse aggregates in concrete, laboratory scale investigations were carried out. In the first stage, studies were carried out to understand the properties of materials used. In the second stage, the strength characteristics were determined using OB-WR as partial replacement for coarse aggregates.

2.1 Cement

Ordinary Portland cement (Grade 53) with Blaine fineness of 300 m^2/kg and specific gravity of 3.15 was used. Physical properties of the cement used in the production of concrete are listed in Table 1.

Table 1. Physical Properties of Cement

Sl. No	Properties	Values Obtained	Requirement as per IS 12269:2013	Remarks
1	Specific Gravity	3.15	----	The cement satisfies the requirement for 53 grade OPC stipulated by IS 12269:2013. Tests are conducted as per guidelines of IS 4031.
2	Standard Consistency (%)	29	----	
3	Fineness (m^2/kg)	300	Should not be < 225	
4	Initial Setting Time (min)	60	Should not be < 30	
5	Final Setting Time (min)	450	Should not be > 600	
6	Soundness (mm) (By Le Chatelier Mould)	2	Should not exceed 10 mm	

2.2 River sand (Fine aggregates)

Locally available river sand conforming to zone II of Table 4 in IS 383:1970, passing through 4.75mm sieve was used. The sand was free from organic matter and silt. The properties of sand such as fineness modulus and specific gravity were determined as per IS 2386-1963 (Part I). The physical properties of sand are shown in Table 2, and grading curve is shown in Figure 1.

Table 2. Physical Properties of Fine Aggregates

Sl. No	Property		Value
1	Specific Gravity		2.70
2	Bulk Density	Loose	1440 kg/m^3
		Compacted	1700 kg/m^3
3	% Of Voids		38%
4	Moisture Content		Nil
5	Water Absorption		1%

Fineness modulus = 2.51

Since the fineness modulus of river sand is 2.51, the sand can be considered as fine sand, as the range of fineness modulus to be considered as fine according to IS 383 is 2.2~2.6.

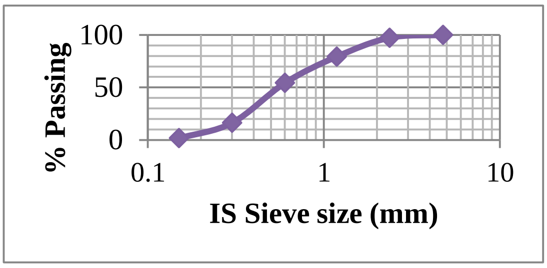

Figure 1. Grading Curve of River Sand

2.3 Crushed stone (Coarse aggregates)

Crushed granite aggregates of maximum size 20 mm (20mm to 4.75mm) conforming to IS 2386 (Part III, IV): 1963 were used in the present investigation. The aggregates were composed of a mixture of rounded and angular aggregates. The various properties of aggregates are determined as per IS 2386 (Part III, IV): 1963 and the specifications are checked as per IS 383: 1970 requirements. The physical properties of coarse aggregates are shown in Table 3.

2.4 Overburden Waste Rock (OB-WR)

The iron ore OB-WR was collected from Hospet, Bellary district of Karnataka state in India (Figure 2). Sampling was done as per IS 2386 (Part III, IV): 1963. The average values of physical properties of the OB-WR are given in Table 3. The grading curve of OB-WR is shown in Figure 3. The aggregate test was performed on OB-WR and it is as per IS code given in Table 4.

Figure 2. View of Iron Ore Mine While Waste Rock Samples Were Collected

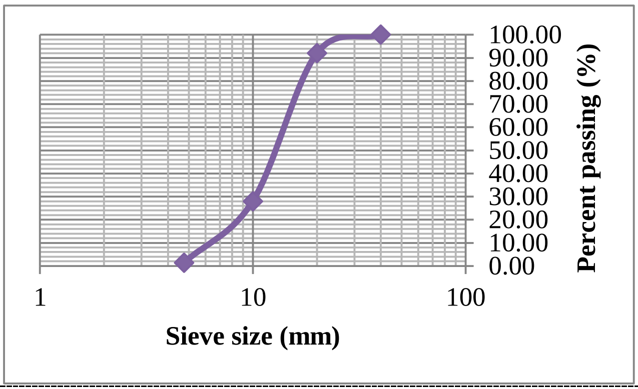

Figure 3. Grading Curve of Overburden Waste Rock

Table 3. Physical properties of overburden waste rock

Sl. No	Property	Crushed stone	Overburden waste rock
1	Specific Gravity	2.8	2.84
	Loose (kg/m^3)	1370	1354
2	Bulk Density		
	Bulk Density Compacted (kg/m^3)	1670	1658
3	Moisture Content	NIL	NIL
4	Water Absorption (%)	0.5	0.45

Table 4. Aggregate test for overburden waste rock (OB-WR) as coarse aggregates

Test	Property	IS code	Limit	OB-WR values
Aggregate Impact Test (%)	Toughness	IS: 2386 (Part 4)	30	7.69
Los Angele's Abrasion Test (%)	Hardness	IS: 2386 (Part 5)	40	12.8
Crushing Test (%)	Crushing Strength	IS: 2386 (Part 4)	35	30.76
Soundness Test (Magnesium Sulphate) (%)	Durability	IS: 2386 (Part 5)	18	0.60

2.5 Water and Superplasticizer

Tap water was used for concreting. Superplasticizer, is chemical admixtures used to reduce the water content in a mixture. Sulfonated naphthalene formaldehyde polymer admixture ("Conplast SP 430") was used to improve the workability of concrete (Table 5).

Table 5. Properties of Conplast SP 430

Specific Gravity	1.20
Chloride Content	Nil
Solid content (%)	40
Operating Temperature (°C)	10 to 40
Colour	Dark brown liquid

2.6 Chemical composition of Overburden waste rock

The various metal oxides present in OB-WR are analysed for there concentration (%) by X-Ray Fluorescence (XRF) investigations.

Table 6. Semi-qualitative analysis of the major and minor elements of studied aggregates based on XRF investigations

Sl. No.	Metal Oxide	Concentration (%)
1	Na_2O	1.402
2	MgO	6.347
3	Al_2O_3	4.643
4	SiO_2	42.861
5	P_2O_5	0.179
6	SO_3	0.39
7	K_2O	0.131
8	CaO	7.377
9	TiO_2	1.449
10	Cr_2O_3	0.104
11	MnO	0.803
12	Fe_2O_3	33.52
13	NiO	0.105
14	CuO	0.141
15	RuO_2	0.142

2.7 Methodology

The volumetric method was used for the proportion design of the mixture. In this study, M40 grade concrete is designed and cement is used as the binder material. The water-binder ratios were 0.40, 0.45, and 0.5, and overburden waste rock (OWR) as coarse aggregate were added at volume replacement ratios of 0%, 20%, 40%, 60%, 80% and 100%. Workability of concrete was determined as per IS 1119 (1999). A 10cm*10cm*10cm cubical concrete specimen was made and solidified. The specimens were placed and cured in water for varying curing days as per IS: 516–1959. The compressive strength was tested at the ages of 3, 7, 14, and 28 days as per IS: 516-1959. Multiple regression analysis is used to analyse the laboratory results with the predicted values.

3. Experimental results and analysis

3.1. Physical properties and Chemical composition

In this study, 10–12 mm sizes crushed stone and overburden waste rock (OB-WR) used as the coarse aggregate (Fig. 1). The specific gravity of the crushed stone and the OB-WR were 2.8 and 2.85, respectively. The water absorption of OB-WR was measured to be 0.45. Slake durability test was also conducted with respect to IS10050-1981 to determine the stability of OB-WR against fragmentation and weakening.

- The physical properties of OPC Grade 53 are presented in table 1 and the observed results satisfy the requirement as per IS 12269:2013.
- River sand was considered as fine aggregate and the physical properties are presented in table 2 as per IS code and the gradation curve is as shown in Fig 2.
- The physical properties of crushed stone and overburden waste rock (OWR) is presented in table 3 and 4. The specific gravity of overburden waste rock is 2.85 and is with water absorption of 0.45. The material properties were tested for OB-WR as per IS 2386 such as impact test, Los Angele’s abrasion test, crushing test and soundness test. The results indicated that the OWR satisfies the requirement.
- Slake durability test was also conducted with respect to IS10050-1981 to determine the stability of OB-WR against fragmentation and weakening. The test identified the slake durability of OB-WR as 98.193%.
- The semi-qualitative analysis of the major and minor elements of OB-WR based on XRF investigations was done (Table 7).

3.2. Workability

Workability and consistency of fresh concrete are two closely related properties. Workability is that property of freshly mixed concrete which determines the ease and homogeneity with which it can be mixed, transported, placed, compacted and finished. Consistency refers to the degree of solidity or fluidity of a material. The concrete slump test is an empirical test that measures workability of fresh concrete. The slump values for the different concrete mix are shown in table 7. Concrete was designed for 25-55 mm range of slump (figure 4). Water cement ratio and superplasticizer content was kept constant for all mixes.

Table 7. Slump value for concrete mixes with OB-WR

w/c	**0.4**	**0.45**
Mix	**Slump (mm)**	**Slump (mm)**
Control mix (100:0)	55	55
OB 20 (80:20)	50	55
OB 40 (60:40)	50	55
OB 60 (40:60)	45	50
OB 80 (20:80)	40	45
OB 100 (100:0)	40	45

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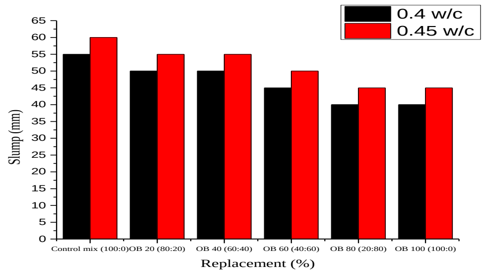


Figure 4. Slump for various concrete mixes

3.3. *Compressive strength*

The specimens were tested at 3, 7, 14, 90 and 28 days of curing (Figure 5 and 6) and the results are graphical represented in the Figure 7 and 8. From the test results it was observed that, compressive strength increased with increase in OB-WR. The increase was prominent in 28 days strength. It depicts that compressive strength of specimens containing 40% OWR was higher than that of control concrete at 28 days. The strength of concrete increased with 100% replacement with OB-WR compared to the normal concrete.

Figure 5. Concrete moulds

Figure 6. Test for Compressive strength

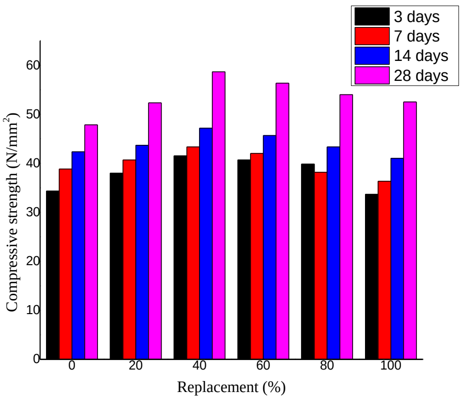


Figure 7. Compressive strength for w/c 0.4

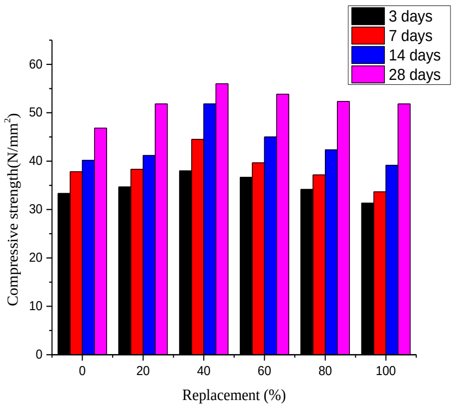


Figure 8. Compressive strength for w/c 0.45

3.4. *Multiple regression analysis*

A Regression model was developed for compression strength with respect to curing days and % replacement with OB-WR as shown in Equations a and b. In order to evaluate the realistic models, a backward elimination method was used as the test procedure. Analysis of variance were performed to observe the essential parameters carried out in statistical models for compressive strength with respect to curing days (3, 7, 14 and 28 days) and 5 replacement levels (0%, 20%, 40%, 60%, 80% and 100%. With significant of 96.47 and 96.5 repectively for 0.4 and 0.45 water-cement ratio. Influenceof parametric level of the compressive strength obtained were compared using (ANOVA) with Minitab 17, where the P-values equal to or smaller than 0.05 were considered to be statistically significant (Table 8,9, 10, 11). The plot is showin in figure 7 and 8 for the predicted and obtained values.

Table 8. Anova analysis for various concrete mixes with OB-WR for 0.4 water cement ratio.

Anova analysis for 0.4 water cement ratio							
Source	**DF**	**Seq SS**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**	**R2**
Regression	4	1016.96	1016.96	254.239	129.920	0.000	
Curing days (Cd)	1	866.87	197.06	197.056	100.700	0.000	
Replacement % (Rp)	1	0.04	89.41	89.415	45.690	0.000	
Replacement %*replacment % (Rp2)	1	140.36	140.36	140.36	71.720	0.000	96.47
Curing days * replacement % (Cd*Rp)	1	9.69	9.69	9.69	4.950	0.000	
Error	19	37.18	37.18	1.957			
Total	23	1054.14					

Regression model:

CS (N/mm^2)= 30.723+0.5340 Cd+ 0.2158 Rp- 0.002424 Rp*Rp+ 0.001955 Cd*Rp → (a)

Table 9. Coefficients for various combinations at 0.40 water cement ratio

Term	**Coefficient**	**SE coefficient**	**T-Value**	**P-Value**
Constant	33.723	0.938	35.940	0.000
Curing days	0.534	0.0532	10.030	0.000
Replacement %	0.2158	0.0319	6.760	0.000
Replacement % * replacement %	-0.002424	0.000286	-8.470	0.000
Curing days * replacement %	0.001955	0.000879	2.230	0.038

Table 10. Anova analysis for concrete mixes with 0.45 water cement ratio with OB-WR

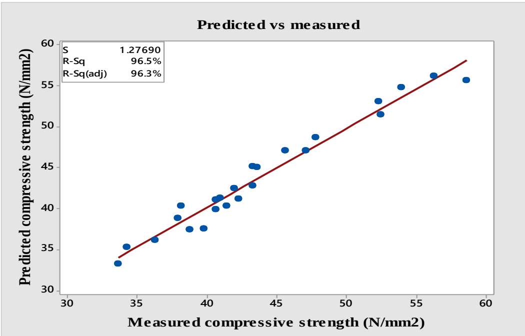
Anova Analysis for 0.45 water cement ratio							
Source	**DF**	**Seq SS**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**	**R2**
Regression	4	1016.96	1016.96	254.239	129.920	0.000	
Curing days (Cd)	1	866.87	197.06	197.056	100.700	0.000	
Replacement % (Rp)	1	0.04	89.41	89.415	45.690	0.000	
Replacement %*replacment % (Rp2)	1	140.36	140.36	140.36	71.720	0.000	96.50%
Curing days * replacement % (Cd*Rp)	1	9.69	9.69	9.69	4.950	0.038	
Error	19	37.18	37.18	37.18			
Total	23	1054.14					

Regression model

CS (N/mm^2)= 33.723+0.5340 Cd+ 0.2158 Rp- 0.002424 Rp*Rp+ 0.001955 Cd*Rp → (b)

Table 11. Coefficients for various combinations at 0.40 water cement ratio

Term	Coefficient	SE coefficient	T-Value	P-Value
Constant	33.723	0.938	35.940	0.000
Curing days	0.534	0.0532	10.030	0.000
Replacement %	0.2158	0.0319	6.760	0.000
Replacement % * replacement %	-0.002424	0.000286	-8.470	0.000
Curing days * replacement %	0.001955	0.000879	2.230	0.038



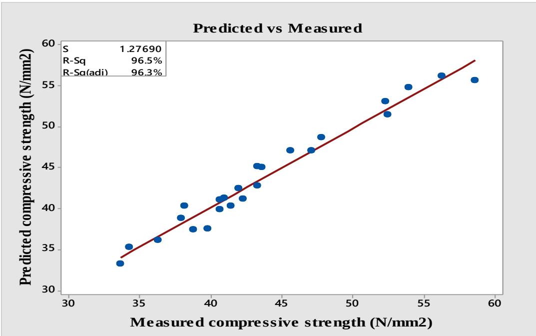


Figure 9. Predicted vs Measured for 0.4 w/c **Figure 10.** Predicted vs Measured for 0.45 w/c

4. Conclusions

In this paper the effect of use of OB-WR on the properties of concrete were studied and it can be concluded that,

i) The physical properties were determined and the specific gravity is 2.85 which is higher than the crushed stone with water absorption of 0.45.

ii) The impact test, Los Angeles Abrasion test, crushing test and soundness test revealed that, the results are within the limits with reference to IS: 2386-1963 and OB-WR can be considered as a construction material for road works.

iii) The workability of all the concrete mixes increased upto 40% replacement with OB-WR and decreased thereafter with reference to the crushed stone. This is because of the water cement ratio and size and shape of the aggregates.

iv) The Compressive strength of the concrete shows an upward trend till 40% OB-WR used as coarse aggregate in concrete. This is mainly because of the favorable chemical composition of OB-WR.

v) Based on the multiple regression analysis, R^2 obtained was 96.5 of the total variations in the observed compressive strength test. The test reveals that, curing days > percentage replacement with IOT. The measured property values and those calculated from the regression model are fairly close which indicates that the developed models could be effectively used, with acceptable accuracy, at the preliminary stage of the design to predict the Compressive strength in the construction industry.

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