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Physico-Mechanical Properties of Concrete with Industrial Waste - A Case Study

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Abstract - A few waste materials, such as demolition waste, steel slag, quarry dust, fly ash are dumped in landfills. This causes environmental issues and pollution. The present study aims to examine the effect of replacing two types of waste materials i.e., quarry dust and steel slag as partial replacement of cement and sand respectively. Cement was replaced partially with quarry dust between 5 to 20% with 5% intervals and sand was replaced by 75% steel slag consistently for all the concrete mixes. The concrete cubes, beams and cylinders were tested for their strength characteristics by measuring compressive strength, flexural strength and splitting tensile strength. The maximum increase of 4%, 34% and 38% in compressive, flexural and splitting tensile strength respectively was observed with 15% quarry dust replaced with cement and 75% steel slag replaced with sand. Based on the present experimental study, partial replacement of these waste materials shall mitigate the issues occurring due to storage and also by utilizing these materials in concrete as replacement for cement and sand resulting in higher strength properties compared to the naturally available construction materials.

***Keywords*:** Quarry dust, steel slag, compressive strength, flexural strength, splitting tensile strength, waste materials.

1. Introduction

Concrete is the most essential building material used in construction industry. Due to the depleting natural resources, demand for recycled materials is increasing in construction industry. A few major materials which are used as replacement for cement are fly ash, GGBS (Ground Granulated Blast Furnace Slag) and Silica fume. In the present study, quarry dust is considered as partial replacement of cement and 75% steel slag as replacement of sand based on the previous literature. Quarry dust is a by-product of the crushing process. During quarrying, the rock is crushed into different sizes and during this process the dust is generated which is called as quarry dust and this is the waste dumped in landfills which poses severe which might cause environmental issues. Steel slag, a by-product of steel making, is produced during the separation of the molten steel from impurities in steel-making furnaces. These materials are considered as marginal materials in the present study. A brief literature on the study of concrete properties with quarry dust and steel slag are discussed in this section. An experimental investigated was made by using stone dust passing from 200 mm sieve and 100 mm sieve as cement and sand replacement respectively. Cement was replaced partially with stone dust by 3, 5, and 7 percent. Similarly, sand was replaced with stone dust by 15 to 50 % with an increase of 5%. Based on the test results, the compressive strength obtained increased by 21.33% and 22.76% with 35% replacement of sand and 3% replacement of cement with sand dust respectively with reference to the control mortar. It was observed that, there was an increase in strength with 100% replacement of sand with quarry dust [1]. Granite Quarry Dust (GQD) was used as replacement of Natural River Sand (NSR) varying from 0 to 100% in volume. Incorporating GQD as complete replacement of NRS was found to give similar mechanical and durability properties as that of conventional concrete incorporating NSR. It was further observed that water demand to obtain the targeted workability reduced significantly. Optimum composition was obtained at 60% replacement of NSR by GQD. Mechanical, flexural and durability properties such as water absorption, total porosity, intrinsic air permeability and capillary absorption had positive improvement up to 60% [2]. The natural coarse aggregates were partially or completely replaced by Recycled Coarse Aggregate (RCA) and Steel Slag Aggregate (SSA). It was observed that RCA and SSA had unfavourable effect on air content of fresh concrete and workability, especially for replacement more than 25%. SSA enhanced mechanical properties whereas RCA had negative effect on these properties. Hence RCA was partially replaced by SSA and maximum strength was obtained at 67% replacement. Modulus of elasticity of RCA mixes increased with replacement by SSA [3]. Quarry dust was used as a partial substitute in two grades of high strength concrete (HSC) mix, 60 MPa and 70 MPa, with quarry dust quantities varying from 10% to 40%. The compressive strength obtained for both the grades of concrete was at 20% replacement, therefore the optimum percentage obtained is at 20%. The workability of fresh concrete and compressive strength and other mechanical properties declined with addition of quarry dust and this was compensated by using rice husk ash as a mineral admixtures and suitable superplasticizer [4]. The granite dust replaced as fine aggregate achieved enhanced dense and compact concrete mixes. The mechanical properties such as compressive strength, split tensile strength and flexural strength were found to increase up to optimal percentage replacement. Durability attributes such as abrasion resistance and corrosion resistance were found to increase up to optimal percentage replacement whereas properties such as water absorption and carbonation depth were found to decrease up to optimal percentage replacement [5].

Monotonic and impact compression test was conducted on a series of cylinders with partial replacement of fine aggregate with steel slag varying from 10% to 40% by volume. Results showed that compressive strength of steel slag sand concrete was found to increase and then decrease with addition of steel slag. Replacement with steel slag resulted in increased stiffness and brittleness whereas failure mode was found to be similar to that oft of conventional concrete. Optimal content of steel slag to obtain improved performance of concrete was found to be 20% [6]. Properties of concrete containing steel slag was studied with 5-year curing, properties like compressive strength, porosity, morphology and composition of hydration products were studied. Results showed that concrete with steel slag replacement had low compressive strength compared to conventional concrete for same water to binder ratio whereas long term properties were found to improve with decrease in water to binder ratio. With higher content of steel slag, it resulted in higher compressive strength, lower porosity, very low permeability was obtained at 5 years. It was found that steel slag particles were found unreacted after 5 years [7]. Effect of energy optimising furnace (EOF) steel slag as partial replacement of course aggregate with quarry dust as binding material, was studied for three grades of concrete (20, 30 and 40 MPa). Various concrete mix proportion of modified slag varying from 0% to 100 was prepared, results showed that a mix proportion of 1:6:14 (cement: quarry dust: slag aggregate) was most suitable mix. Evaluating compressive strength and splitting tensile strength showed that maximum compressive strength was obtained with 25% replacement of natural course aggregate and maximum splitting tensile strength was found to obtain at 25% replacement of natural aggregate [8]. Three concrete mixtures using steel slag, crystallized slag and limestone aggregates as partial replacement for natural aggregates were studied with constant water to binder ratio of 0.27. It was observed that rough surface of artificial aggregate improved bond between aggregate and cement paste and hence increased compressive strength of concrete. Ground granulated blast furnace slag (GGBFS) and silica fume were used as supplementary cementing materials and it was found that concrete with 20% dosage of GGBFS had similar properties as that of silica fume [9].

Based on the literature study, the quarry dust was generally used as sand replacement in laboratory studies. The present study focuses on utilization of quarry dust as cement replacement and steel slag as fine aggregate replacement for greener construction.

2. Experimental study

2.1. Materials

Ordinary Portland Cement (OPC) Grade 53, river sand, coarse aggregates, potable water and waste materials as replacement for cement and river sand are quarry dust and steel slag and Conplast SP 430 is used as a superplasticizer for a workable concrete. The physical and chemical properties are given in Table 1 and Table 2 and Table 3. The grain size distribution of steel slag and river sand is shown in Figure 1.

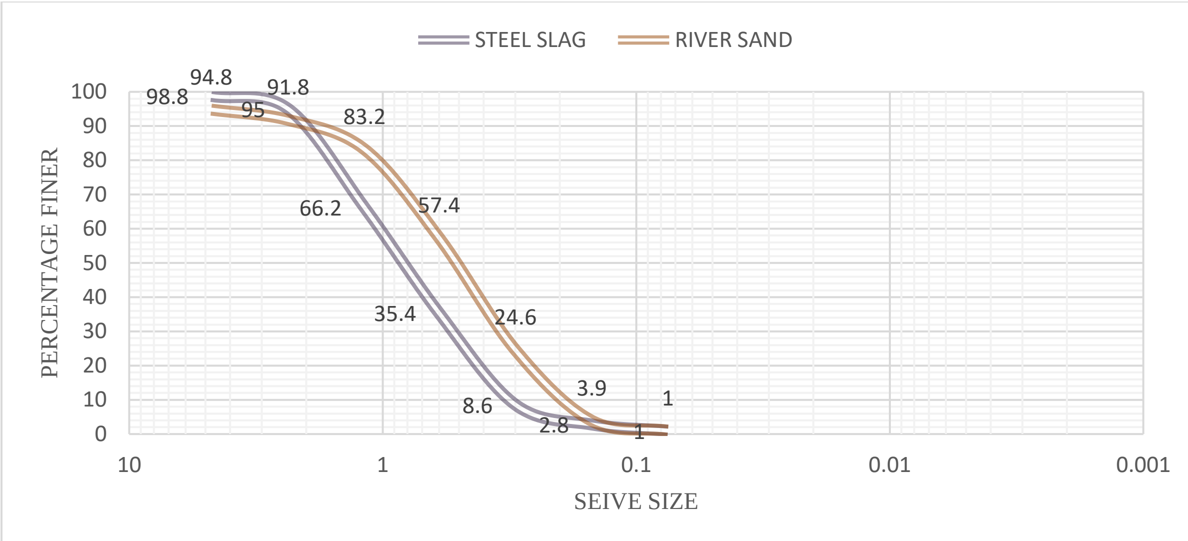

Fig. 1: Grain size distribution of steel slag and river sand.

Table 1: Physical properties of cement.

Sl No.	Test	Results	IS 12269 (Part II)
1	Normal consistency	27	
2	Specific gravity	3.14	3.1-3.15
3	**Setting time (min)**		
A	Initial	128	≥ 30
b	Final	367	≤ 600
4	**Compressive strength (days)**		
a	3	28.8	≥27
b	7	38.3	≥37
c	28	54.7	≥53

Table 2: Physical properties of aggregates.

Aggregate	Specific gravity	Water absorption (%)	Unit weight (g/cc)
Coarse aggregates	2.75	0.25	1.55
River sand	2.69	1	1.33
Steel slag	2.37	1.8	1.36
Quarry dust	2.53	1.2	-

Table 3. Chemical composition of quarry dust.

Elements	% Composition
SiO_2	62.47%
Al_2O_3	18.73%
Fe_2O_3	6.55%
CaO	4.82%
Others	7.41%

2.2. Mix Proportion

M40 grade concrete was considered for mix design as per IS 10262 [10] with water cement ratio of 0.4. The fine aggregates have been replaced by steel slag by 75% constantly for all the concrete mixes by varying percentages of quarry dust as cement replacement from 5% to 15% with 5 % intervals. The details of the mix proportions designed for the present study are given in Table 4.

Table 4: Mix proportion.

Mix	Cement Kg/m^3	W/C ratio	Water Lit/m^3	F.A. Kg/m^3	C.A. Kg/m^3	Quarry dust Kg/m^3
QD1	18.56	0.40	7.81	10.5	58.62	0.97
QD2	17.59	0.40	7.81	10.5	58.62	1.95
QD3	16.70	0.40	7.81	10.5	58.62	2.93
QD4	15.63	0.40	7.81	10.5	58.62	3.90

Note: W/C- Water-Cement Ratio; F.A. – Fine Aggregates; C.A. – Coarse Aggregates

2.3. Methodology

The concrete mix is considered based on the mix design for M40 grade using concrete mixer by placing the materials and mixing it for 5 minutes. A total of 24 cubes, 15 beams and 15 cylinders were cast for all the concrete combinations. The samples were cast and dried at room temperature for 24 hours and demoulded and water cured for different curing days i.e., 3, 7, 14 and 28 days curing. All the mechanical properties were tested to determine the strength of the concrete mixes consisting of varying percentages of quarry dust as replacement of cement and 75% of steel slag considered as replacement of river sand for all the mixes. Figure 2(a) and Figure 2(b) shows the casted concrete moulds and the water curing of concrete samples for the present study.

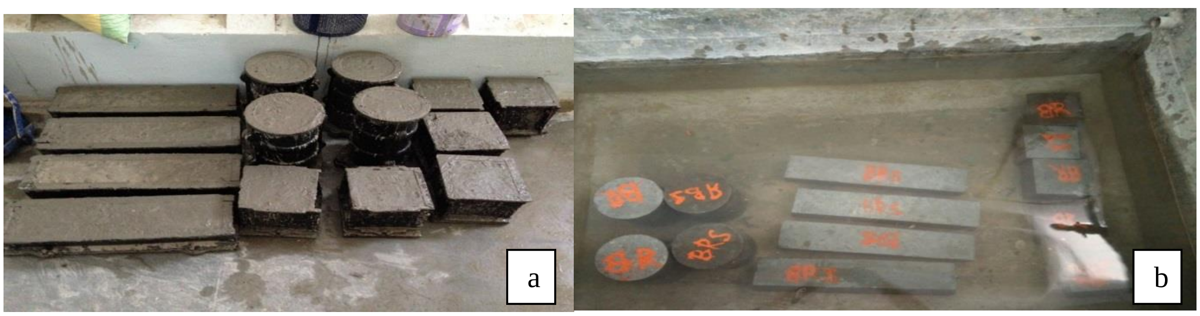

Fig. 2: (a) Casted concrete moulds (b) Water curing of concrete samples.

3. Result and Discussion

3.1. Compressive strength

The compressive test was carried out for various concrete mixes partially replacing the cement with quarry dust varying from 5 to 15 % with 5% interval and 75% of steel slag as sand replacement using Universal Testing Machine (UTM) for 100*100*100 mm cubes (Figure 3). The compressive strength of all specimens was computed for 3, 7, 14 and 28 curing days. Increase in trend of compressive strength was observed with increase in quarry dust and 75% steel slag content. The maximum strength was obtained at 15%. Decrease in compressive strength was observed at 5% replacement whereas further increase in percentage of quarry dust increased compressive strength of mix up to 15% (Figure 4).

Fig. 3: Test on concrete cubes for compressive strength.

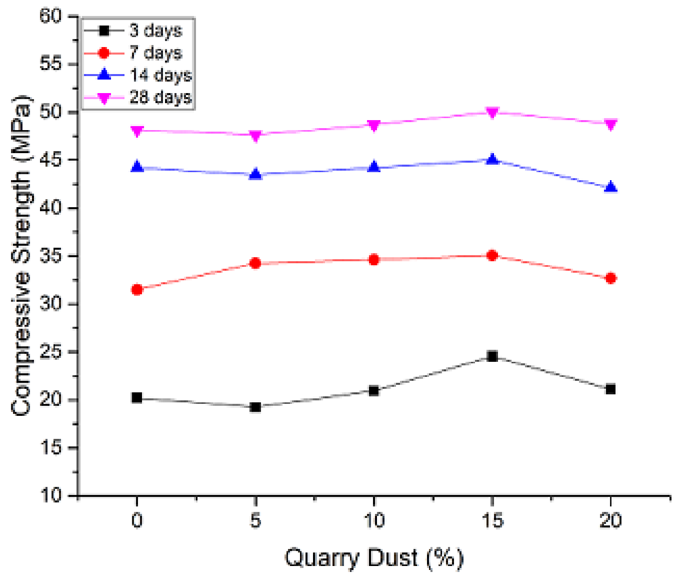

Fig. 4: Trend of compressive strength with quarry dust and steel slag.

3.2. Flexural strength

The flexural strength of concrete specimens was tested using three point loading method (Figure 5). Three samples with dimensions 100*100*500 mm beams were casted and tested at 28 days cured samples. The optimum strength of 6.1 MPa was observed at 15% replacement of cement with quarry dust and 75% replacement of sand with steel slag with reference to the control mix (Figure 6).

Fig. 5: Test on concrete beams for flexural strength.

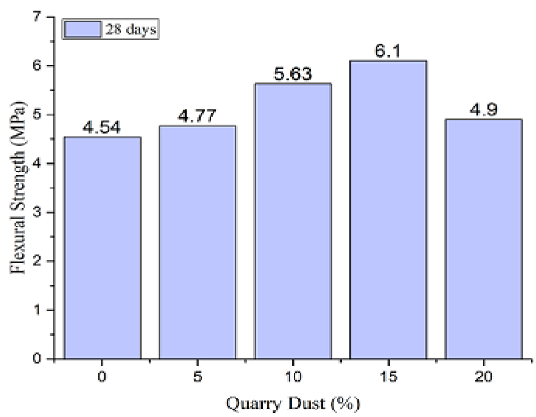

Fig. 6: Flexural strength with quarry dust and steel slag.

3.3. Splitting tensile strength

The concrete cylindrical specimens were tested using UTM (Figure 7). Three samples with dimensions 150*300 mm cylinders were casted and testing for tensile strength. An increase in trend was observed and the optimum strength was observed at 15% replacement of cement with quarry dust and 75% replacement of sand with steel slag with reference to the control mix (Figure 8).

Fig. 7: Test on concrete cylinders for splitting strength

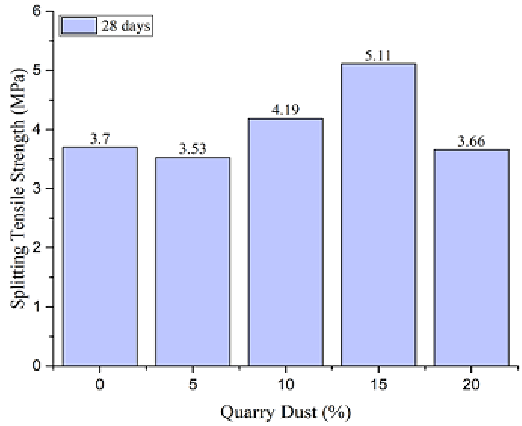

Fig. 8: Splitting tensile strength with quarry dust and steel slag

3.4. Pearson correlation

Pearson correlation coefficient is a statistical measure of a linear relationship between paired data. In the present research, curing days and compressive strength are the paired data sets. Correlation can describe the strength and suggest for the absolute value of r. The compressive strength increased with increase in curing period for 3, 7, 14 and 28 days. The Pearson correlation coefficient values range from 0.779 to 0.891. The results are tabulated in Table 5, and represent a strong positive correlation between the two variables.

Table 5: Pearson correlation of curing days and compressive strength with respect to various replacement levels of quarry dust with steel slag in concrete.

Mix	Pearson correlation	P-Value
0% replacement by quarry dust+0 steel slag	0.779	0.221
5% replacement by quarry dust+75% steel slag	0.831	0.169
10% replacement by quarry dust+75% steel slag	0.835	0.165
15% replacement by quarry dust+75% steel slag	0.846	0.154
20% replacement by quarry dust+75% steel slag	0.891	0.109

4. Conclusion

The laboratory studies conducted to determine the mechanical properties shows an increasing trend up to 15% replacement and later decreased with further replacement of quarry dust and steel slag. The compressive strength, flexural strength and splitting tensile strength increased by 4%, 34% and 38% respectively with optimum replacement of 15% quarry dust and 75% steel slag. The accuracy of the results was validated by statistical analysis using Pearson correlation. The value of correlation lies between +1 to -1 and the values are in within the range i.e., +0.779 to 0.891. Hence, quarry dust and steel slag can be used as partial replacement of cement and sand respectively without compromising the strength properties. It is found to be economical and also reduces environmental issues and pollution caused due to storage in landfills.

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