A Comparative Study on Using Laterite and Sandstone Aggregates on Mechanical Properties of Concrete

B. C. Gayana, K. Ram Chandar, and Krishna R. Reddy

Abstract Scarcity of natural aggregates in concrete construction is leading to explore the use of alternative materials, especially various industrial waste products. Mining industry is one such major source of waste materials. Sandstone, which is overlying coal seams, is the largest quantity of waste rock being produced by coal mining industry. Laterite is another waste comes from small scale quarries. An attempt is made to assess the use of laterite-GGBS and sandstone as partial replacement for sand in concrete. Sandstone samples were collected from the dumps of a coal mine in south India and laterite samples were collected from different quarries from the southwestern part of India. Various properties of mine waste samples were determined in the laboratory as per IS codes, the properties were found to be very close to that of natural river sand. Mix proportions were prepared for M20 grade concrete. Mechanical properties of concrete with different mixes (0, 25, 50, 75, and 100% replacement with sand) were determined and compared. As a result, the concrete mixes with the replacement of fine aggregates with 100% sandstone increased in strength properties i.e., compressive, splitting tensile, and flexural strength compared to laterite mixes, where the strength properties decreased with increase in replacement levels. This indicates that sandstone can be an effective replacement for the river sand in concrete.

Keywords Aggregates · Mine waste · Compressive strength · Splitting tensile strength · Flexural strength

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1 Introduction

The fine aggregates generally used in concrete is sand from river or sea. Due to the depleting nature of sand and restricted sand mining in many places, researchers are investigating for the best suitable alternative material to replace the river sand partially or fully without compromising the strength and durability characteristics. One of the alternatives could be mine waste. The major concern of waste management in the mining industry is, a large quantity of top layer waste rock to be removed to extract valuable coal or ore. Waste also generated while separating the valuable minerals from the ore, which are called as tailings. Tailings are the processed waste disposed to the tailing ponds. Researchers are investigating the use of these waste materials in the field of construction industry as replacement material for cement, fine and coarse aggregates. This paper is limited to the use of laterite and sandstone in concrete.

Laterite is a semi consolidated rock and is generally rusty red color due to high content of iron oxide. In the investigation on the suitability of laterite-cement mortars, the clay content adversely influenced the strength of the concrete [1]. Laterite has been satisfactorily used as a fill material for foundations and base course for highway construction [2, 3]. Experimental investigations on the properties of laterite in geopolymer concrete were done and the compressive strength obtained was 18 MPa for 28 days curing [4].

Another major waste produced by the mining industry is sandstone. Sandstone disposed in the form of overburden dumps which requires a large amount of area for storage affecting the fertility of the soil [5]. The effects of various parameters on dump stability were investigated. It causes dust pollution and also disturbs the flora and fauna and during the rainy seasons the dumped material may slide into the mine working areas [6]. A study was carried out to use the sandstone for vegetation to improve stability but requires a good amount of additives. So, utilization of it in the field of construction might mitigate the environmental issues of storage and handling of mine waste [7]. The effect of sandstone in brick preparation with incineration bottom ash was observed. With the water–cement ratio of 0.55, the compressive strength of different mix proportion samples was higher than the control mix by 14 MPa [8]. An experimental research was done to examine the suitability of quartz sandstone as a replacement for coarse aggregates. With the increased percentage of replacement of quartz sandstone, the compressive strength, flexural strength, and sulfate attack decrease with reference to control mix [9]. The potential use of sandstone powder as mineral additive to replace cement in concrete was investigated. A decrease in compressive strength by 30% was observed with 50% replacement of sandstone with cement, so 5% silica fume was added to enhance the strength properties and durability properties [10]. Other major mine waste generally used in concrete is iron ore tailings. An extensive survey of the use of mine tailings in the construction industry in the application of concrete pavements [11].

The main aim of the present study is to evaluate the physical and mechanical properties of different marginal materials viz., laterite and sandstone for various applications in the construction industry.

2 Experimental Study

The details of the materials used in the present research work along with the methodology and basic properties are discussed in this section.

2.1 Materials

a. Binder: Cement and Ground-Granulated Blast-furnace Slag (GGBS) are used as binders, the physical properties of the binders used are given in Table 1.
   Cement: Commercially available Ordinary Portland Cement (OPC) Grade 43 was used.
   GGBS: Ground-Granulated Blast-furnace Slag (GGBS) was collected from the nearby plant and partially replaced OPC by 40%. The specific gravity is 2.9.
b. Water: Potable drinking water was used.
c. Fine aggregates: Three types of fine aggregates are used for the study, river sand, laterite, and sandstone. The physical properties of the same are given in Table 2.
   River sand: Locally available river sand was used for the study.
   Laterite: The material was collected from different quarries in the southern part of Karnataka state in India.
   Sandstone: The sandstone samples were collected by random sampling method from a coal mine in south India.

Table 1 Physical properties of OPC and GGBS

Properties	OPC 43	GGBS	Requirements as per Indian standards
Specific gravity	3.12	2.9	3.10–3.15
Initial setting time (min)	71	–	300 (min)
Final setting time (min)	352	–	600 (max)
Fineness (%)	1.7	–	10 (max)

Table 2 Physical properties of aggregates

Properties	River sand	Laterite	Sandstone	Coarse aggregates
Specific gravity	2.64	2.54	2.56	2.74
Water absorption (%)	1.3	10.86	2.25	0.8
Moisture content (%)	Nil	13.77	2.4	Nil
Maximum size (mm)	4.25	4.25	4.25	20
Liquid limit	–	42	–	–
Plastic limit	–	30	–	–
Plasticity Index (PI) (%)	–	12	–	–
Fineness modulus	2.75	2.25	3.05	–

d. Coarse aggregates: Crushed aggregate is used in the present study.

2.2 Mix Preparation, Casting and Curing of Specimen

The nominal mix ratio was designed for the different materials as replacement for fine aggregates in the present research as discussed below:

Laterite: Mix design was done for M20 grade concrete. Cement was partially replaced by GGBS by 40% and fine aggregates were replaced by laterite at 0, 25, 50, 75, and 100% by volume.

Sandstone: Mix design was done for M20 grade concrete. The fine aggregates were replaced with sandstone at 0, 25, 50, 75, and 100% by volume.

The test blocks were prepared with concrete samples casted in different molds depending upon the test requirements. Four cubes of dimension 150 mm × 150 mm × 150 mm accounting to 12 cubes per mix proportion were casted for the compression test. Four cylinders of 150 mm diameter and 300 mm length were casted for the splitting tensile tests and four beams of dimension 500 mm × 100 mm × 100 mm were prepared for the flexural strength tests. Fresh concrete was used for the slump tests. It should be noted that among the 12 cubes prepared for compression tests, four cubes each were cured for three different curing days (3, 7, and 28 days) prior to testing and for cylinder and beam samples only 28 days of curing was considered prior to testing.

2.3 Results and Discussions

Workability: The workability of concrete at fresh state was tested using a slump cone for different mixes i.e., with partial replacement of sand with laterite and sandstone. Workability of concrete with increased dosage of laterite and sandstone are compared. Figure 1 shows a comparison between the workability of different mixes. Based on the study, workability decreased with increase in laterite-GGBS concrete and increased in case of sandstone. This is due to the water holding capacity of laterite. The increase in slump was observed at 20% mix for laterite-GGBS concrete and incase of sandstone concrete, though there was not much difference after 20% replacement there is a considerable increase in slump value.

Compressive Strength: Concrete cubes of 150 mm × 150 mm × 150 mm were casted with increment replacement percentages of laterite and sandstone. The detailed explanation on the compressive strength of laterite-GGBS concrete and sandstone concrete are reported [12, 13]. The comparison trend of compressive strength for laterite and sandstone concrete is shown in Fig. 2a–c. An increase in trend is observed with increase in sandstone replacement in concrete with respect to laterite-GGBS concrete for 3, 7, and 28 curing days.

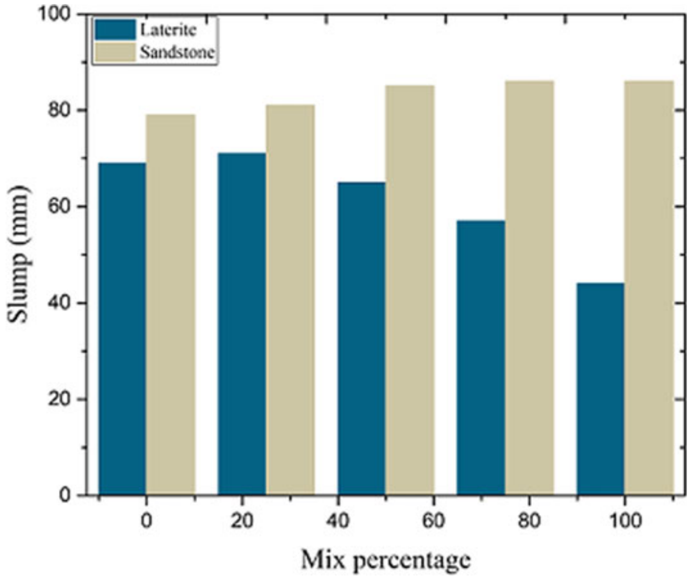

Fig. 1 Workability of laterite and sandstone mixes

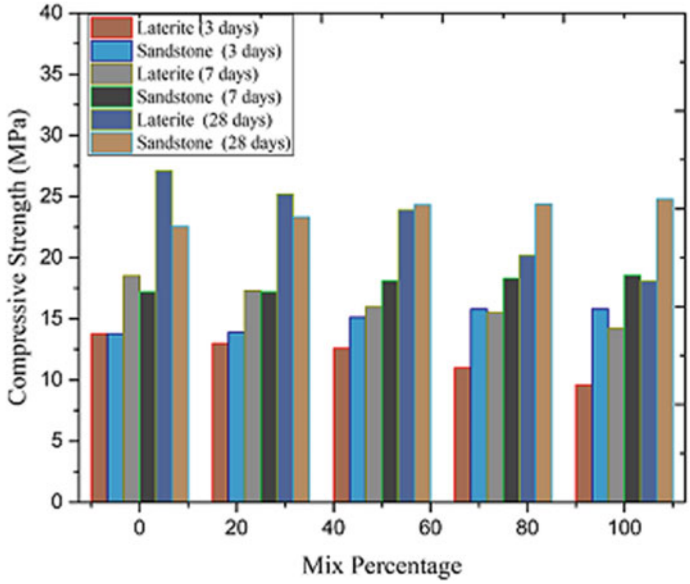

Fig. 2 Comparison of compressive strength of laterite-GGBS and sand stone concrete

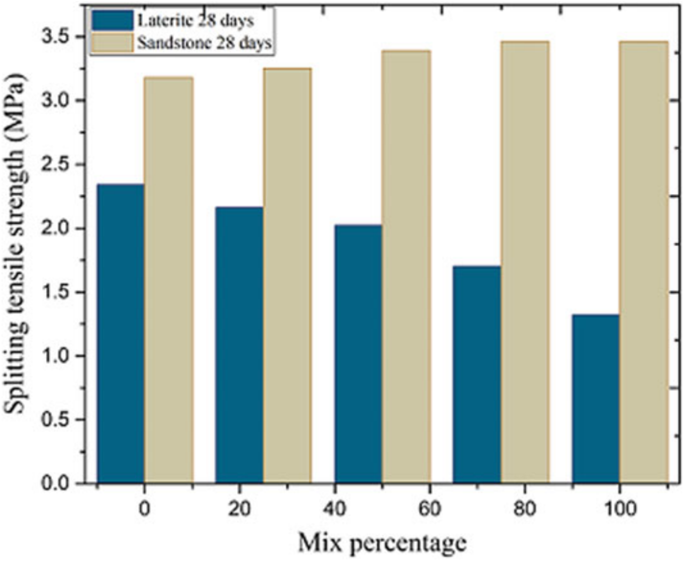

Fig. 3 Comparison of splitting tensile strength

Splitting Tensile Strength: Concrete cylinders of 150 mm × 300 mm were casted with increment percentages of laterite and sandstone. The comparison trend of splitting tensile strength for laterite-GGBS and sandstone concrete is shown in Fig. 3. It is observed that, there is an increasing trend in the splitting tensile strength for sandstone concrete up to 100% replacement and a decreasing trend is observed in laterite-GGBS concrete at 28 curing days. The increase in splitting tensile strength may be due to the bonding between the sandstone aggregates with the binder.

Flexural strength: Concrete prisms of 500 mm × 100 mm × 100 mm were casted with increment replacement percentages of laterite and sandstone. The comparison trend of flexural strength for laterite-GGBS and sandstone concrete is shown in Fig. 4. The flexural strength of sandstone shows an increasing trend compared to the laterite concrete at 28 days curing. The difference is more after 20% replacement.

2.4 Regression Analysis

Statistical model was developed for compressive strength for the different mix percentages and curing days for laterite-GGBS concrete and sandstone concrete.

Prediction Model for Laterite-GGBS Concrete: A regression model was developed to predict the compressive strength of laterite-GGBS concrete. The Eq. 1, was developed considering the mix percentage (Mp), curing days (Cd), and measured compressive strength of laterite-GGBS concrete. The analysis of variance (ANOVA) test summary and parametric estimates are shown in Tables 3 and 4, respectively.

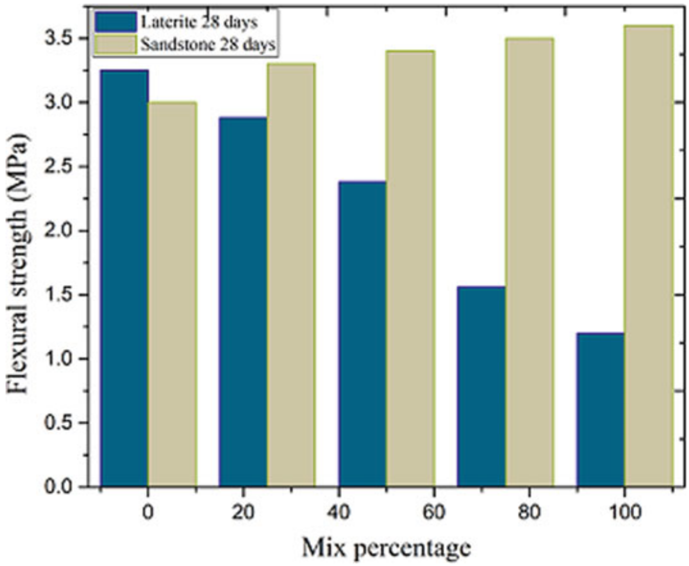

Fig. 4 Comparison of flexural strength

Table 3 ANOVA summary for compressive strength model for laterite

Source	F-value	P-value
Regression	68.99	0.0001
Mp	0.00	0.958
Cd	32.39	0.0001
Mp^2	1.40	0.266
Cd^2	13.55	0.005
Mp * Cd	4.36	0.066

Table 4 Parameter estimates for model for laterite

Variable	Coefficient	Standard error	T-value	P-value
Constant	10.27	1.29	7.95	0.0001
Mp	0.0020	0.0368	0.05	0.958
Cd	1.4200	0.25	5.69	0.0001
Mp^2	−0.0005	0.000438	−1.18	0.266
Cd^2	−0.0279	0.00759	−3.68	0.005
Mp * Cd	−0.0021	0.00102	−2.09	0.066

Notation: Mp = Mix %; Cd = Curing Days

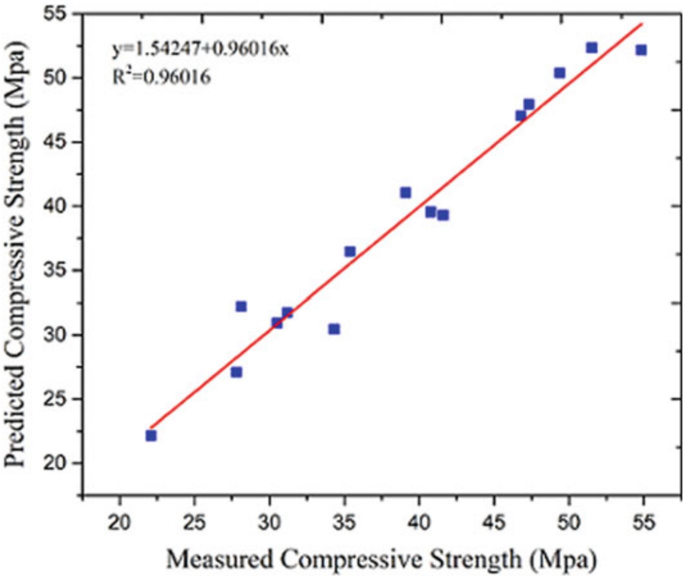

Fig. 5 Predicted versus measured compressive strength

Table 3 indicates that the model is robust and Table 4 shows that all the independent variables except the Mp were significant at a 95% confidence level. The R^2 value obtained is 97.46% and RMSE is 0.8389. The measured versus predicted compressive strength is shown in Fig. 5 and also the error plot is shown in Fig. 6, it is observed that the highest error is 2.09 at sample-12 and lowest error is −1.177 at sample-13.

Regression model for laterite-GGBS concrete:

$$\begin{aligned} CS(MPa) = {} & 10.27 + 0.0020\ Mp + 1.420\ Cd \\ & - 0.000518\ Mp^2 - 0.02792\ Cd^2 - 0.00213\ Mp * Cd \end{aligned} \tag{1}$$

2.5 Prediction Model for Sandstone Concrete

Another model was developed to predict the compressive strength for sandstone concrete. The Eq. 2, was developed considering the mix percentage (Mp), curing days (Cd), and measured compressive strength of sandstone concrete. The analysis of variance (ANOVA) test summary and parametric estimates are shown in Tables 5 and 6, respectively. Table 5 indicates that the model is a good fit and Table 6 shows that all the independent variables except the mix percentage were significant at a 95% confidence level. The R^2 value obtained is 93.59% and RMSE is 0.2458. The measured versus predicted compressive strength is shown in Fig. 7 and also the error

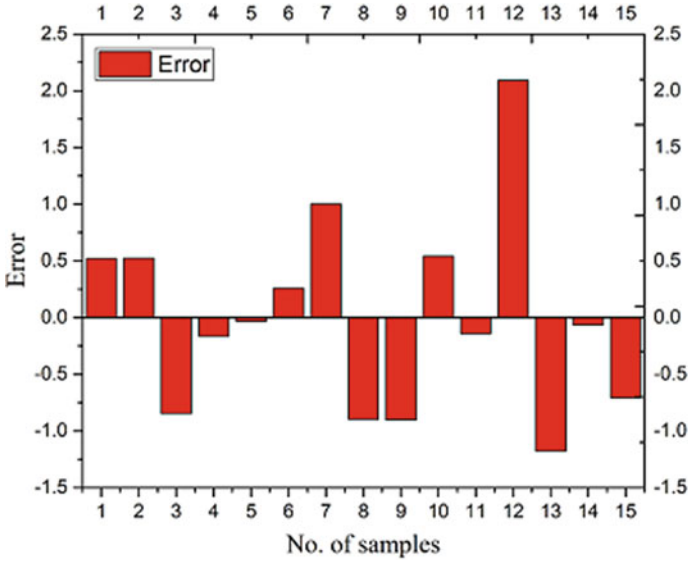

Fig. 6 Error graph for the compressive strength for laterite

Table 5 ANOVA summary for sandstone compressive strength model

Source	F-value	P-value
Regression	433.67	0.0001
Mp	11.80	0.007
Cd	165.65	0.0001
Mp^2	1.67	0.228
Cd^2	71.45	0.0001
Mp * Cd	0.11	0.751

Table 6 Parameter estimates for compressive strength model sandstone

Term	Coefficient	SE coefficient	T-value	P-value
Mp	11.112	0.372	29.87	0.0001
Cd	0.02953	0.0086	3.43	0.007
Mp^2	0.9394	0.0730	12.87	0.0001
Cd^2	−0.000101	0.000078	−1.29	0.228
Mp * Cd	−0.01879	0.00222	−8.45	0.0001
Mp	0.000069	0.000211	0.33	0.751

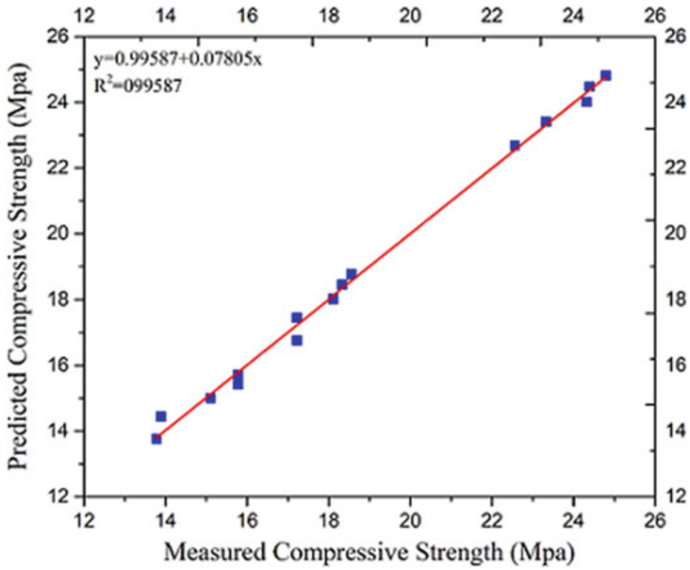

Fig. 7 Predicted versus measured compressive strength for sandstone

plot is shown in Fig. 8, it is observed that the highest error is 0.45 for sample-5 and lowest error is −0.55 fort sample-2.

Regression model for sandstone concrete:

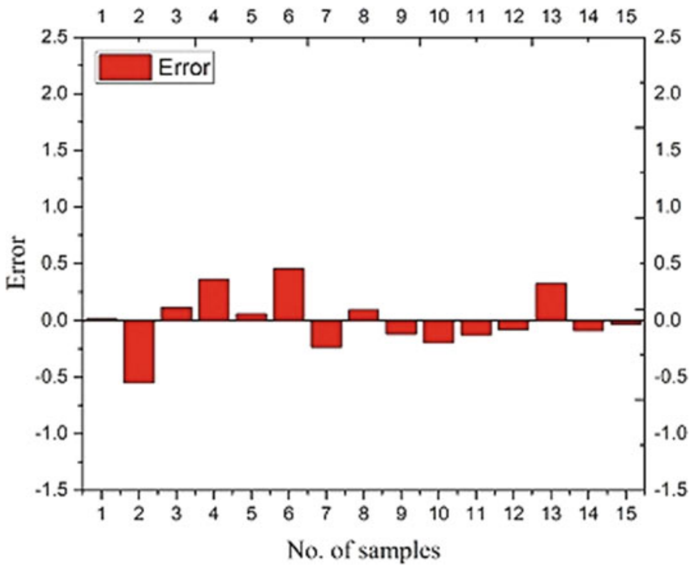

Fig. 8 Error graph for the compressive strength of sandstone

$$\begin{aligned} \text{CS (MPa)} &= 11.112 + 0.02953\,\text{Mp} + 0.9394\,\text{Cd} - 0.000101\,\text{Mp}^2 \\ &\quad - 0.01879\,\text{Cd}^2 + 0.000069\,\text{Mp} * \text{Cd} \end{aligned} \tag{2}$$

3 Conclusions

An experimental study was done to study the suitability of laterite-GGBS and sandstone in concrete as the replacement for conventional fine aggregates and to compare the effectiveness of the both in concrete. The following conclusions are drawn from the study.

The workability of concrete decreased with increase in laterite-GGBS-blended concrete and in the case of sandstone, it increased with increase in sandstone replacement. The decrease in workability in case of laterite-GGBS mix may be due to the water holding capacity of laterite.

For laterite-GGBS blended concrete, the compressive strength decreased by 33.21% with 100% replacement percentage. This could be due to the high water absorption of the laterite. In case of sandstone concrete, the strength gradually increased with increase in sandstone replacement by 9.09% observed for 100% replacement of fine aggregates with sandstone.

The splitting tensile strength and flexural strength were determined at 28 days curing. The split tensile strength and flexural decreased with increase in replacement levels by laterite-GGBS blended and sandstone aggregate, respectively. In case of sandstone, the maximum splitting tensile strength and flexural strength increase was at 100% replacement by 8.81% and 20%, respectively.

Based on the regression analysis, the R^2 obtained for all the concrete mixes above 95% with the P-value of less than 0.005 and RMSE value between 0.2 and 0.8 which can be considered statistically significant model for the concrete mixes. By comparison between the two marginal materials, sandstone was found to be a better model and can be considered as a replacement for fine aggregates in concrete industry without compromising the strength and durability characteristics and also to mitigate the environmental issues due to dumping of these materials at mine sites.

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