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Experimental investigation for partial replacement of fine aggregates in concrete with sandstone

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Abstract. This research study focuses on utilizing sandstone which is overburden waste rock in coal mines to use in concrete as a replacement of fine aggregate. Physical properties of sandstone like water absorption, moisture content, fineness modulus etc., were found to be similar to conventional fine aggregate. Scanning Electron Microscope (SEM) analysis was carried out for analysing elemental composition of sandstone. There was no sulphur content in sandstone which is a good sign to carry the replacement. Fine aggregate was replaced with sandstone at 25%, 50%, 75% and 100% by volume and moulds of concrete cubes and cylinders were prepared. Compressive strength of concrete cubes was tested after 3, 7 and 28 days and split tensile & flexural strength was determined after 28 days. The strength was found to be increasing marginally with increase in sandstone content. Fine aggregate that was replaced by 100% sandstone gave highest strength among all the replacements for the compressive, split tensile and flexural strengths. Though increase in strength was marginal, still sandstone can be an effective replacement for sand in order to save the natural resource and utilize the waste sandstone.

Keywords: coal mine overburden; waste rock; sandstone; fine aggregate; concrete; strength

1. Introduction

Concrete is one of the basic requirements for creation of any infrastructure, buildings, roads, etc. Concrete requires natural aggregates, which are obtained from quarries. The fine aggregates generally used is the river sand. Such deposits do not require much processing other than size grading. Most of the tropical and subtropical countries still depend upon river sand for fine aggregates. But now it is well understood that indiscriminate sand mining causes irrepairable and irreversible damages to the ecological system. Both coarse and fine aggregates are natural resources, once used cannot be replenished.

Sand mining causes many problems to flora and fauna also. Excessive sand mining causes unpredicted water course causing floods in surrounding areas, water pollution etc. A study carried out on Kulsi river, Assam in India revealed that one of the factors that resulted in the decline of

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dolphin population was due to discriminate sand extraction and related disturbances in the river (Mohan 2000). Illegal sand mining has been taking place on the banks of Shimsha river near Kokkare Bellur in Bangalore, Karnataka which has affected the life of avian fauna of that region (Ronnie 2006). A study on East Gonja District of Ghana and Gunnarsholt area of Iceland revealed that sand mining causes loss of farm or grazing lands, enhancement of erosion and loss of vegetation, destruction of landscape, generation of conflicts, loss of biodiversity and dust pollution (Musah 2009).

So there is a need to look for alternative material for fine and coarse aggregates such as mine waste and other industrial waste products. Presently, there are various materials such as recycled fine aggregate, china clay waste, stone dust, robo sand etc., that can be used as partial replacement for fine or coarse aggregates. But many of the times, mine waste is neglected as alternative even though they are available huge in quantity in terms of millions of cu.m. Generally opencast mining generates more waste rock.

In fact, there are two types of mining that are operated as opencast and underground mining. Opencast mining contributes to the maximum production and productivity of many minerals, but it is bound to damage the natural ecosystem due to the removal of waste rock on the overlying coal seam. Such waste rock generally consists of a few meters of top soil followed by shale and sandstone. During opencast mining, the overlying soil is removed and heaped aside to use in future for vegetation. The shale and sandstone are fragmented and heaped in the form of overburden dumps. These dumps occupy a large amount of surface land, which loses its original use/fertility and generally gets soil qualities degraded over a period of time (Barpanda *et al*. 2001). As the dump materials are generally loose, fine particles become highly prone to blowing wind causing dust generation, ultimately leading to dust pollution. These get spread over the surrounding fertile land, flora, disturbing their natural quality and abstains the growth of fresh leaves of the tress. On the other hand, in rainy season, the dumped material may slide into mine workings or in to the surround lands due to high hydro-static pressure develops during rain in the dumps (Sastry and Chandar 2013). Sometimes the dumps may fail due to ground vibrations produced due to blasting from adjacent bench workings (Chandar *et al*. 2016). It was found that overburden dump materials are usually deficient in major nutrients. Hence, most of the overburden dumps do not support any kind of vegetation (Chandar *et al*. 2015). A positive utilization of such waste rock can not only saves land but also reduces environmental problems in the surrounding area.

In general, coal mine overburden contains shale and sandstone in layers, which are geologically sedimentary formation. Shale is the most abundant sedimentary rocks, representing nearly 80% of them. Mineralogically made of montmorillonite (Kesavulu 2009). Montmorillonite is actually highly active clay (Punmia and Jain 2005). Since using clay in concrete is not possible, using of shale is also not possible. On the other hand sandstone contains more than 90% of the particles as sand and thus sandstone can be used in concrete (Kesavulu 2009).

Many researchers have tried to use different waste generated from mines in different ways. Chandar *et al*. (2016) used laterite waste produced from quarries for partial replacement of fine aggregates in GGBS blended concrete. Some other researchers have made attempts to use sandstone for backfilling/stowing in mines and also for partial replacement of fine aggregates in concrete to use in construction and pavements. Some of the typical outcomes of their studies are summarized below.

A study on the coal mine overburden/crushed over burden for stowing purpose was taken up that has 93% of sand content with average specific gravity of 2.53. Compressibility characteristics also revealed that it was useful for stowing in underground mines, if the material passed through

0.15 mm sieve (Prashanth *et al*. 2010). A study on Jharia coal mining fields in India revealed that 98% of the particles were retained on 75 μm and higher sieve sizes while washing sandstone (Rai *et al*. 2011). A study conducted in Raniganj coal field found that there was 96% of sand content in the over burden and the presence of clay and silt particles was very low. In this material, the presence of nitrogen, potassium and phosphorus contents are very less and the waste rock is not useful for plantation (Yaseen *et al*. 2012). Another study carried out on the coal mine overburden of the Basundhara (west) opencast mine revealed that the sand content in the samples are more than 80%. The study suggested that the fresh mine spoil to attain the soil features of native forest soil through the process of reclamation takes 28 years, provided the spoil habitat is not subjected to any other interferences like erosion, vegetational degradation, etc., which is a very difficult task to achieve (Maharana and Patel 2013).

The replacement of fine aggregate with sandstone in concrete paving block showed the maximum strength at 50% and beyond that it reduced the strength of the paving block (Santosh *et al*. 2013). Beams made with coarse aggregate as sandstone resulted in excessive deflection under service loads due to lower stiffness of sandstone aggregates, but it was within the acceptable limits (Kumar *et al*. 2007).

Sandstone tends to have low compressive strength than natural aggregates and have a scattered variance on its mechanical properties and very sensitive to time dependent mechanical deterioration. Sandstone tend to perform well in dry conditions but in wet conditions it is poor when used for unbound forest roads (Rodgers *et al*. 2009)

Yilmaz and Tugcrul (2012) replaced coarse aggregate with sandstone aggregate, the results obtained revealed that, subarkose-arkose, sublitharenite-litharenite and arkose aggregates (different grades of sandstone) which have clay cement caused approximately 40-50% reduction in concrete strength when compared to subarkose, quartz sandstone and arkose aggregates which have carbonate cement, because these aggregates resulted in weaker bonding between aggregate and cement than others. Five different aggregate types such as gabbro, basalt, quartzite, limestone and sandstone were found to produce high strength concrete. It was found that gabbro concrete showed the highest compressive strength and while sandstone showed the lowest compressive strength (Uysal 2012).

Quartz sandstone obtained from Dholpur, eastern most part of Rajasthan state of India was used as replacement of coarse aggregates. Increase in compressive strength resulted for varied ratios of combined gradation and decreased after attaining a specific gradation due to segregation and increase in void spaces due to the usage of bigger sized aggregates (Kumar *et al*. 2016).

Wu *et al*. (2016) investigated the effect of replacing sandstone with incineration bottom ash and different water-cement ratio and different aggregate sizes in concrete brick preparation. The compressive strength of 11 different mix proportions exceeded the traditional red bricks by 14 MPa with water-cement ratio of 0.55. Permeability co-efficient was within general permeable pavement specifications. Hence, it was recommended to use for bicycle ways, sidewalks and landscaping but not for high traffic flow.

Yang *et al*. (2013) made numerical and experimental investigations on the effect of pore structures on the static mechanical properties of porous sandstone. The laboratory test verified the developed physical models which have consistent geometric and statistical characteristics of pores with those of real sandstone. The split mechanical properties of the physical models have good agreement with the predictions of numerical simulations.

Faiz *et al*. (2015) studied the effect of different micro-silica (MS) contents of 5, 10 and 15 wt.% as partial replacement of cement on mechanical and durability properties of high volume fly ash-recycled aggregate concrete (HVFA-RAC) containing 50% class F fly ash (FA) and 35% recycled concrete aggregates (RCA) as partial replacement of cement and coarse aggregates respectively. The study established that MS contributes to the sustainability of HVFA-RAC significantly by improving the mechanical and durability properties of concrete. The effect of replacing fine aggregate by Tailing Material (TM) and cement by Fly Ash (FA) on standard size specimen for mechanical properties were evaluated by Sunil *et al*. (2015). In this study, the concrete mix of M40 Grade was adopted with the water cement ratio equal to 0.40. It resulted in good strength properties with 35% replacement of fine aggregates with TM and it was observed that with 20% replacement of cement with FA resulted in increase in strength properties. Cement and sand was replaced by stone dust by considering stone dust passing No. 200 sieve for cement replacement and stone dust passing No. 100 sieve for sand replacement and various mechanical properties were determined Imrose *et al*. (2014). The result indicated that, with replacement of 35% of sand and 3% of cement with stone dust, the compressive strength increased by 21.33% and 22.76% respectively while tensile strength increased by 13.47%. Belkacem *et al*. (2014) studied the effect of sand on the fracture and mechanical properties of sand concrete on four different types of sand i.e., dune sand (DS), river sand (RS), crushed sand (CS) and river dune sand (RDS). The results obtained show that the particle size distribution of sand has influenced all the properties of sand concrete since the sand having the highest diameter and the best particle size distribution gave the best fracture and mechanical properties. Crushed sand gave good results compared to river and dune sand due to its angular shape.

Some other researchers have used some destructive methods to study the internal structure and other characteristics of sandstone. Feijoo *et al*. (2015) investigated the efficiency of electrokinetic techniques for desalination of two different kinds of rocks: granite and sandstone. It resulted in effective removal of salt concentration by 100% in granite samples compared to sandstone which resulted in not very high decrease at intermediate levels where slight enrichments were observed.

Biao *et al*. (2016) studied the electromagnetic radiation (EMR) characteristics and mechanical properties during sandstone deformation and fracture after high temperature treatment. EMR signals and acoustic emission (AE) signals were produced during the process of sandstone deformation and fracture. Under conditions of instability and failure, the EMR frequency changed notably, and the EMR intensity reached the maximum. Application of EMR count as a damage variable reflected the sandstone deformation and fracture process.

After going through the literature thoroughly, a systematic analysis was carried out by replacing the sand in concrete with sandstone in incremental order till 100%.

2. Materials and methods

2.1 Materials

The primary objective while collecting a sample for laboratory analysis is that its composition should be representative of the conditions that exists in the field. The procedure involves the random collection of material at the site over the designated area and combining them to form a composite sample for analysis. A total of 5 samples were collected from a sandstone dump in southern part of India (Fig. 1).

2.1.1 Cement

Ordinary Portland Cement of 43 grade of ACC brand used for experimental purpose. Physical properties of cement were determined as per IS8112-2013 and tabulated in Table 1.

(a) (b)

Fig. 1 Sandstone overburden dump of an opencast coal mine where the samples were collected

Table 1 Physical properties of cement

Properties	Experimental results	As per IS code requirement
Specific gravity	3.11	3.10-3.15
Initial setting time (min)	70.00	30 (min)
Final setting time (min)	350.00	600 (max)
Fineness (%)	1.70	10 (max)

2.1.2 Aggregates

Locally available river sand used as fine aggregate initially. Gravels constitute major part of coarse aggregates. Physical properties of river sand and gravels were determined as per IS 383-1970 and the details are given in Table 2.

Table 2 Physical properties of aggregates

Property	Fine aggregates	Coarse aggregates
Specific gravity	2.64	2.74
Water absorption (%)	1.30	0.80
Moisture content	Nil	Nil
Maximum size (mm)	4.25	20

2.1.3 Water

Water is an important ingredient of concrete as it actually participates in the chemical reaction with cement. The water used was clean and free from deleterious matter.

2.2 Experimental investigations

The experimental programme involved combining the water cement ratio, percentage of cement, fine and coarse aggregates and replacing sand with sandstone as fine aggregate in varying proportions. Mix design was done and the mix proportions are given in Table 3. Cement, sand, coarse aggregate and fine aggregate were thoroughly mixed in dry state so as to obtain uniform color. Then, the required water as per the designated water cement ratio was added to the dry mix in order to obtain uniform mixture. The compaction factor test and slump test were carried out on fresh concrete and the respective values were recorded for all the trial mixes. The moulds with standard dimensions of i.e., 150×150×150 mm were filled with concrete in 3 layers by poking with tamping rod and vibrated by the table vibrator. The vibrator was used for 30 seconds and it was maintained constant for all specimens. Along similar lines, the beams of size 100×100×500 mm and cylinders of size 150 mm diameter and 300 mm length were also casted. A total of 60 cubes, 20 cylinders and 20 beams were casted for 5 different mix proportions of 0%, 25%, 50%, 75% and 100% for fine aggregate replaced with sand. The samples (cubes, beams and cylinders) were air dried for a period of 24 hours and then they were weighed to find out their weight prior to curing. Thereafter, they were immersed in water. The cubes were allowed for 3, 7 and 28 days curing while the beams and cylinders were allowed for 28 days curing. The samples were tested for their respective strengths.

Table 3 Composition of concrete

Material	Weight (Kg/m^3)	Mix proportion with reference to cement
Water	197.16	0.50
Cement	394.32	1.00
Fine aggregate	678.16	1.72
Coarse aggregate	1148.39	2.91

3. Results and analysis

This section deals with the results obtained from laboratory tests carried out.

3.1 Physical properties

3.1.1 Particle size analysis

Sieve analysis was carried out for 5 different samples of sandstone and the size distribution data is tabulated in Table 4. It was observed that, in all the 5 samples, 92% of the particles are greater than 75 μm size, which is the most important property to use it as a replacement for fine aggregate. This result is in close agreement with the studies carried out by Maharana and Patel (2013) and Keshavulu (2009) who have reported that sandstone has more than 80 and 90 per cent particles more than 75 μm respectively. Fig. 2 represents the grain size distribution which shows all the samples have similar particle size range.

Fineness modulus of samples varied from 2.23 to 2.30, with an average value of 2.25. It indicates that the material will come under fine sand which is perfectly suitable as replacement for fine aggregates.

Table 4 Cumulative percentage passed for all samples

IS sieve size (micron)	Cumulative percentage retained (%)				
	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
4750	1.56	1.24	3.05	2.80	1.90
2360	3.75	3.88	5.68	5.90	3.20
1180	15.57	14.26	16.38	18.52	15.32
600	41.43	42.95	41.44	38.93	39.91
300	71.79	72.54	75.77	71.91	70.98
150	89.51	90.54	87.74	88.78	91.90
75	93.83	93.33	94.61	92.99	93.14
Fineness modulus	2.23	2.25	2.30	2.26	2.23

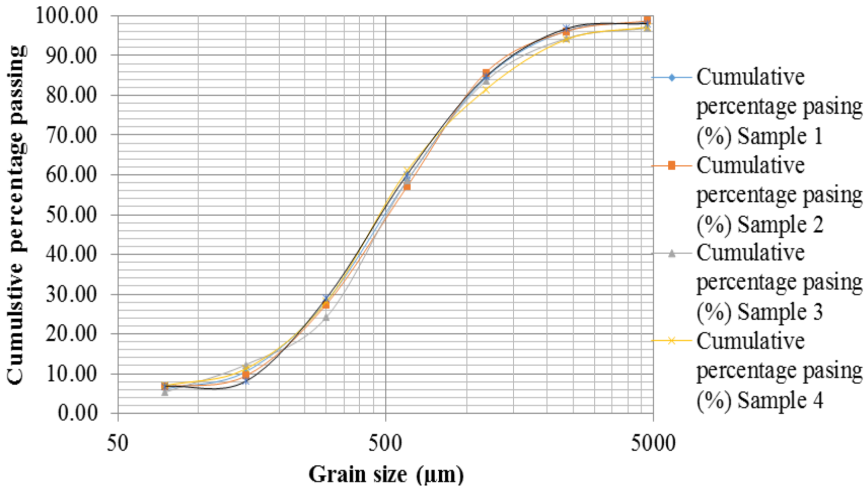


Fig. 2 Particle size distribution for all samples

3.1.2 Specific gravity and water absorption

Specific gravity of the material was tested using Pycnometer and the results are given in Table 5. The specific gravity of 5 samples 2.56, 2.57, 2.55, 2.57 and 2.55. There is no deviation for any samples for more than 0.02 with average specific gravity of 2.56 for the mix design purposes. This value is closer to conventional fine aggregate and also very close to the previous studies reported by Prashanth *et al.* (2010). So the weight of the cubes do not change much when the fine aggregate is replaced with sandstone.

Water absorption test is continuation of specific gravity test and done with pycnometer for 5 samples. The water absorptions for 5 samples was found to be 2.21%, 2.33%, 2.24%, 2.19% and 2.28% with an average of 2.25%. The water absorption for Conventional fine aggregate was found to be 0.5%. So when the concrete is prepared with replacing sandstone as a replacement, the extra amount of water has to be added to prevent the concrete from the workability point of view.

Table 5 Cumulative percentage passed for all samples

Parameter	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
Weight of saturated surface-dry sample (gm)	510.23	511.16	512.49	511.2	515.17
Weight of pycnometer or gas jar containing sample and filled with distilled water (gm)	1860.38	1862.85	1860.37	1860.58	1865.85
Weight of pycnometer or gas jar filled with distilled water only (gm)	1545.25	1546.15	1544.28	1544.21	1546.87
Weight of oven-dried sample (gm)	499.21	499.53	501.26	500.26	503.71
Apparent Specific Gravity	2.71	2.73	2.71	2.72	2.73
Specific gravity, (G)	2.56	2.57	2.55	2.57	2.57
Water absorption	2.21	2.33	2.24	2.19	2.28

3.1.3 Moisture content

Moisture content of the material was tested as per IS 2720 (P-2)-1173 and results were tabulated in Table 6. The moisture content of samples was found to vary between 2.3% to 2.5% of weight of the material. So, the material is easy for transportation. For the design consideration an average value of 2.4% is considered, so the results obtained here are satisfactory.

Table 6 Moisture content of sandstone

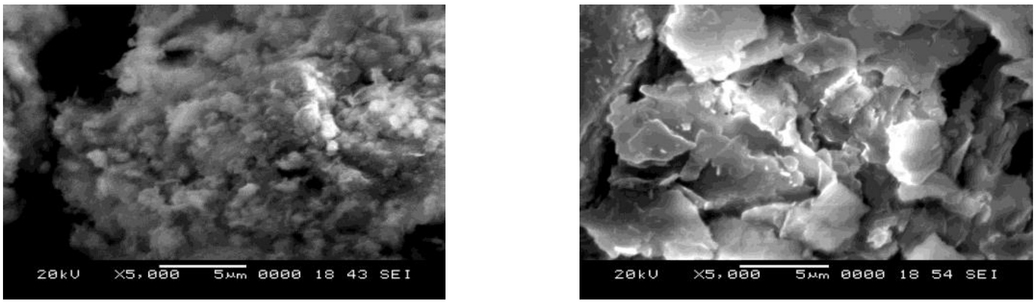
Trial no.	Cup no.	Weight of cup (gm)	Weight of cup with sample (gm)	Weight of cup with sample after oven drying (gm)	Weight of water (gm)	Moisture content (%) $W = \frac{W_w}{W_s} \times 100$
1	52	33.35	79.80	78.67	1.13	2.49
2	56	32.65	85.98	84.67	1.31	2.52
3	62	34.12	82.19	81.08	1.11	2.36
4	57	33.96	81.76	80.64	1.12	2.40
5	66	32.87	80.23	79.19	1.04	2.25

3.2 Scanning electronic microscopic analysis

Elemental composition of sandstone tested for all the samples using SEM with EDAX (Fig. 3). Along with different elements, there is presence of magnesium in small dosage as shown in Fig. 4. It was found that sandstone primarily consists of oxygen, aluminium, iron, silicon and traces of Titanium and potassium in the form of oxides. The typical results of a sample are given in Table 7. From the results, it can be stated that there are no traces of sulphur content in the samples. Hence, there is no threat from internal sulphate attack from sandstone to concrete internally. There is no calcium content in the samples, so it can resist the acid attack.

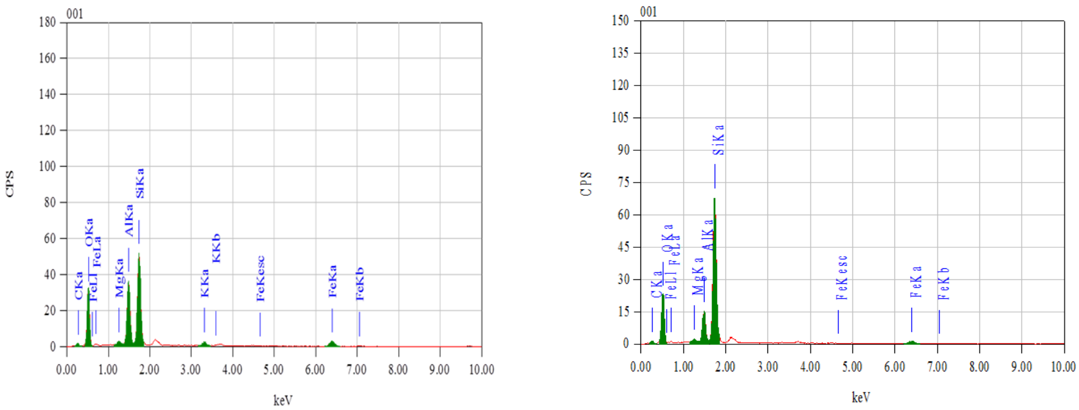
3.3 Properties of concrete

Concrete tested for different properties like workability when it is fresh and hardened



(a) (b)

Fig. 3 Microscopic view for the sample



(a) (b)

Fig. 4 Different elements in the sandstone sample

Table 7 SEM analysis results

Elements	Percentage of element (%) for sample-1	
	Face 1	Face 2
C	20.48	12.21
O	55.46	61.46
Al	11.87	16.19
Si	7.40	8.97
Ti	0.28	0.23
Fe	4.52	0.95

properties such as compressive strength, split tensile strength and flexural strength.

3.4 Workability of fresh concrete

Workability of concrete is tested for each mix when it was casted as per IS1199-1959. The workability was getting increased with increase in replacement of fine aggregate with sandstone as it is fine compared with conventional fine aggregate. In all the cases, the type of slump was true.

The variation of workability with sandstone is shown in Fig. 5. As the replacement of sandstone increased from zero to 75%, the slump values increased gradually, from 75 to 100% replacement of sandstone there was not much change in the slump values.

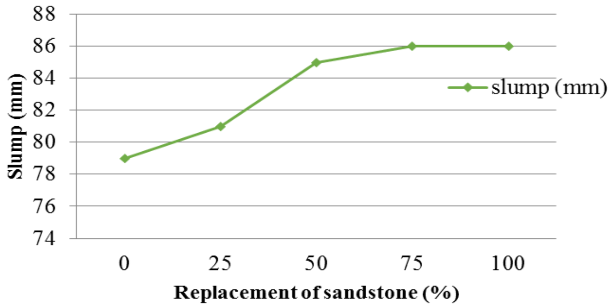


Fig. 5 Variation of slump with sandstone

3.5 Compressive strength

Compressive strength of hardened concrete was tested as per IS:516-1959 for curing of 3, 7 and 28 days for 4 samples each and average was calculated (Fig. 6). Summary of the tests results are given in Table 8.

Fig. 6 Compressive strength

Table 8 Comparison of strength with increase in sandstone replacement in fine aggregates

Sl. no.	Percentage replacement of sandstone (%)	Compressive strength (N/mm^2)		
		3 days	7 days	28 days
1	0	13.78	17.22	22.56
2	25	13.89	17.22	23.33
3	50	15.11	18.11	24.33
4	75	15.78	18.33	24.39
5	100	15.78	18.56	24.79

3-days strength: The 3-days strength at 0% replacement was found to be 13.78 N/mm^2 which is quite good for M20 grade concrete. The variation of strength with replacement of sandstone is shown in Fig. 7. With 25% replacement, compressive strength was increased just by 0.8% with an average of 13.89 N/mm^2. From 25% to 50% replacement, strength was increased by 8.07%, which is a noticeable variation. From 50% to 75% strength got increased by 4.44% and for 100% replacement it showed same strength as 75% replacement. Overall the 3-days compressive strength was increased by 14.51% for 100% replacement with sandstone. To correlate the increase in compressive strength with increased percentage of replacement of sandstone, regression analysis was done. The regression Eq. (1) is shown below

$$CS=0.5889X+13.1 \tag{1}$$

Where,
CS=Compressive strength
X=Percentage of replacement
The regression co-efficient is 0.898, which shows very good correlation.

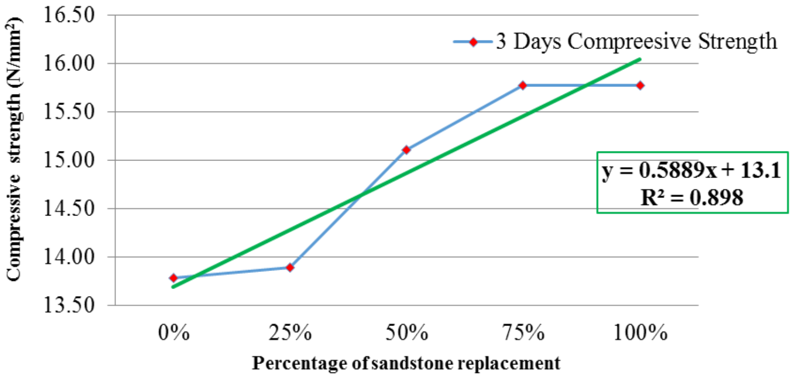


Fig. 7 Variation of 3-days compressive strength with sandstone replacement

7-Days strength: 7-Days strength of concrete with 0% replacement found to be 17.22 N/mm^2. The variation of strength with different percentage of replacement is shown in Fig. 8. For the replacement of 25% with sandstone there is no increment in strength. From 25% to 50%, strength was increased by 5.16%. From 50% replacement to 75% replacement strength was increased by 1.21%. From 75% to 100% strength was increased by 1.25%. Overall the 7-days compressive strength was increased by 13.4% for 100% replacement with sandstone. To correlate the increase in compressive strength with increased percentage of replacement of sandstone, regression analysis was done (Fig. 8). The regression Eq. (2) is shown

$$CS=0.3778X+16.756 \tag{2}$$

Where,
CS=Compressive strength
X=Percentage of replacement
The regression co-efficient is 0.9031, which shows very good correlation.
28-Days strength: Even though the 3 and 7 days compressive strength was determined, but the

most required strength for the concrete is after 28-days curing. The strength of concrete can be usually in terms 28-days compressive strength. 28- Days strength of concrete with 0% replacement found to be 22.56 N/mm^2. For the replacement of 25% with sandstone there was 3.33% increase in strength. From 25% to 50% replacement, strength was increased by 4.28%. From 50% to 75% replacement strength was increased by 0.36%. From 75% to 100% strength was increased by 1.6%. Overall, for 100% replacement the strength was increased by 9.84% when compared with control mix. The strength noted at 100% replacement was 24.78 N/mm^2. Fig. 9 showing the variation of compressive strength with percentage of replacement.

To correlate the increase in compressive strength with increased percentage of replacement of sandstone, regression analysis was done. The regression Eq. (3) is as shown

$$CS=0.55X+22.228 \tag{3}$$

Where,
CS=Compressive strength
X=Percentage of replacement
The regression co-efficient is 0.9102, which shows very good correlation.

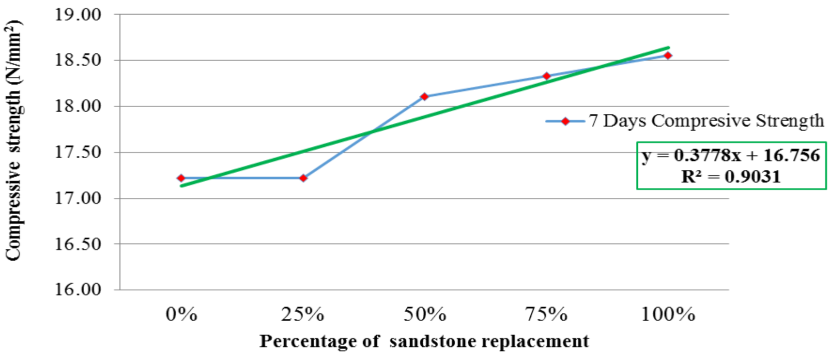


Fig. 8 Variation of 7-days compressive strength with sandstone replacement

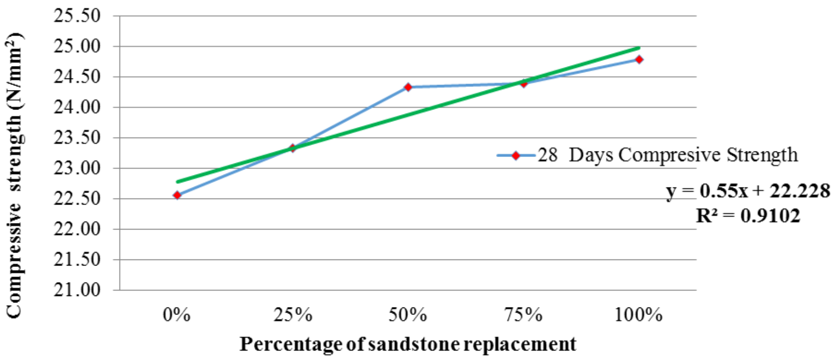


Fig. 9 Variation of 28-days compressive strength with sandstone replacement

It can be observed from Table 8, that for 3, 7 and 28 days compressive strength in all the cases the strength increased with the increase in replacement of fine aggregate with sandstone (Fig. 10).

The main reason might be the presence of small percentage of cementitious content that was present in sandstone. But the total strength increase was less than 10 per cent, which is very marginal.

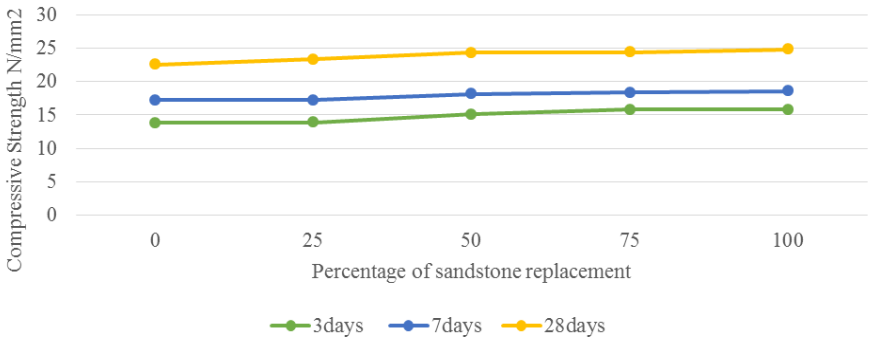


Fig. 10 Compressive strength comparison for different curing days with different % of sandstone replacement

Earlier studies carried out by Wu *et al.* (2016) investigating the effect of replacing sandstone with incineration bottom ash and different water-cement ratio and different aggregate sizes in concrete brick preparation shown that the compressive strength of 11 different mix proportions exceeded the traditional red bricks by 14 MPa with water-cement ratio of 0.55. Though there is a slight variation of these studies with ours, but the results are in close relationship.

3.6 Split tensile strength

Concrete is not usually expected to resist the direct tension because of its low tensile strength and brittle nature. However, the determination of tensile strength of concrete is necessary to determine the load at which the concrete samples may crack. The cracking is a form of tension failure as shown in Fig. 11.

The split tensile strength was conducted as per IS: 5816-1999. At 0% replacement, it is found to be 3.18 N/mm^2 which is quite good for M20 grade concrete. The variation of strength with replacement of coal mine overburden is shown in Fig. 12. With the 25% replacement, strength was increased by 2.20%. From 25% to 50% replacement, strength was increased by 4.25%. From 50% to 75% strength got increased by 2.18% and for 100% replacement it showed same strength as 75% replacement. Overall the split tensile strength was increased by 8.46% for 100% replacement with sandstone.

To correlate the increase in split tensile strength with increased percentage of replacement of sandstone, regression analysis was done. The regression Eq. (4) is as shown

$$TS=0.0778X+3.1182 \tag{4}$$

Where,
TS=Split tensile strength
X=Percentage of replacement
The regression co-efficient is 0.9167, which shows very good correlation.

(a)

(b)

Fig. 11 Arrangement for split tensile strength and cracked cylinders

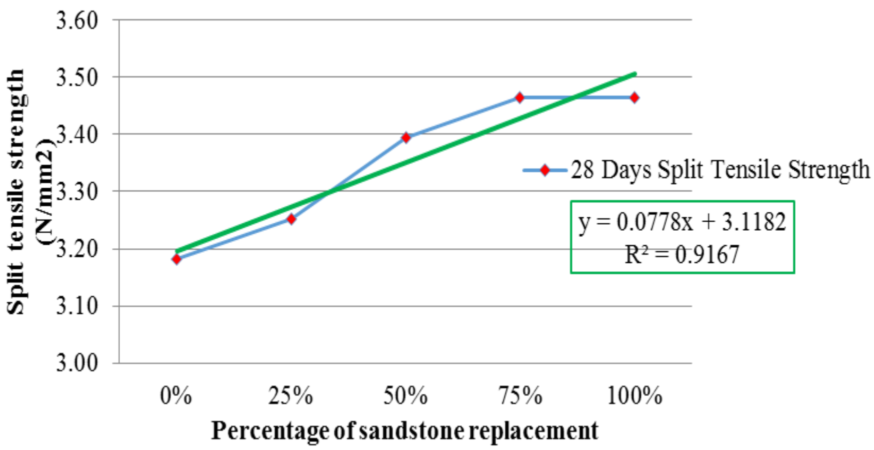


Fig. 12 Variation of split tensile strength with sandstone replacement

3.7 Flexural strength

Flexural strength was tested as per IS: 516-1959 for curing of 28 days for 4 samples and average was calculated (Fig. 13). The flexural strength at 0% replacement found to be 3.00 N/mm^2 which is quite good for M20 grade concrete. The variation of strength with replacement of coal mine overburden is shown in Fig. 14. With the 25% replacement, strength was increased by 10%. From 25% to 50% strength was increased by 3.03%. From 50% to 75% strength got increased by 2.94% and for 100% replacement it got increased by 2.85%. Overall the flexural strength was increased by 20% for 100% replacement with sandstone. 25% per cent replacement gave higher strength. On the other hand, studies carried out by Kumar *et al*. (2016) revealed that there is a decrease in flexural strength by 8 per cent by adding sand stone. Generally up to 10 per cent variation is insignificant.

To correlate the increase in flexural strength with increased percentage of replacement of sandstone, regression analysis was done. The regression Eq. (5) is as shown

$$FS=0.14X+2.94 \tag{5}$$

Where,
FS=Flexural strength
X=Percentage of replacement
The regression co-efficient is 0.9245, which shows very good correlation.


Fig. 13 Flexural Strength arrangement and cracked beams

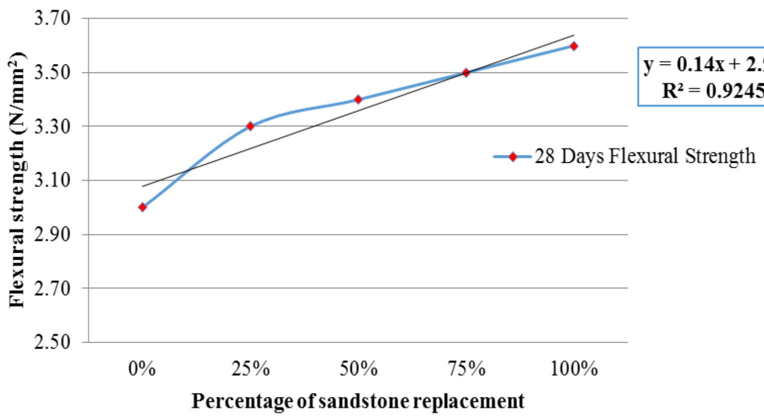


Fig. 14 Variation of flexural strength with sandstone replacement

Comparison among the strengths obtained for 28 days curing for various percentages of replacement of sandstone with base mix. It can be observed in Table 9 that, there is increase in the strengths for 100% replacement of fine aggregates in concrete as shown in Fig. 15. As the values of split tensile strength and flexural strength are almost same, the both curves are over lapping in Fig. 15. Though the increase in strength is very marginal, still it is advisable to replace fine aggregate with sandstone because the natural sand utilization can be reduced and at the same time dumping problem, dump stability problem at the mine site can be avoided.

The summary of the regression analysis done with equations corresponding to compressive strength, split tensile strength and flexural strength with the R^2 values are given in Table 10.

Table 9 Strength comparison for 28 days curing for varying percentage replacement of sandstone

Sl. no.	Percentage replacement of sandstone	28 days curing		
		Compressive strength (N/mm^2)	Split tensile strength (N/mm^2)	Flexural strength (N/mm^2)
1	0	22.56	3.18	3.00
2	25	23.33	3.25	3.30
3	50	24.33	3.39	3.40
4	75	24.39	3.46	3.50
5	100	24.79	3.46	3.60

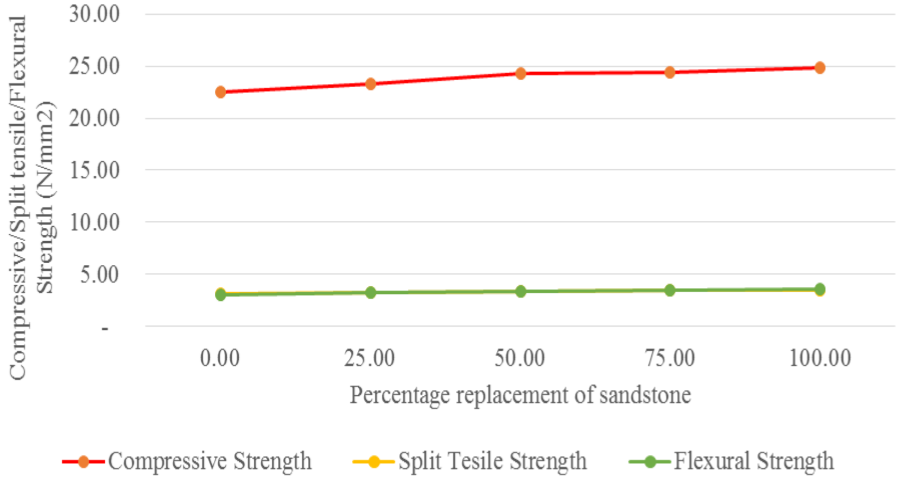


Fig. 15 Strength comparison for 28 days curing for varying percentage replacement of sandstone

Table 10 Summary of regression equation with R2 value-table

Curing days	Compressive strength		Split tensile strength		Flexural strength	
	Equation	R^2	Equation	R^2	Equation	R^2
3 days	CS=0.5889+13.1	0.898	-	-	-	-
7 days	CS=0.3778x+16.756	0.9031	-	-	-	-
28 days	CS=0.6333x+19.389	0.8699	TS=0.55x+22.228	0.9102	FS=0.0778+3.1182	0.9167

CS: Compressive strength, TS: Tensile strength, FS: Flexural strength

Table 11 shows the variation of strength with reference to base mix. From the results it can be observed that there is increase in strength percentage with increase in sandstone replacement as fine aggregate compared with base mix. Flexural strength and split tensile strength exhibited higher variation when compared with compressive strength. This concludes that sandstone can be a very effective replacement for fine aggregates in cement, without compromising on strength properties and at the same time large quantity of sandstone available can be effectively utilized for useful purpose. Studies conducted by Kumar (2006) also revealed that sandstone can be effectively used on even high-performance concrete.

Table 11 Percentage of variation in strength with respect to base mix

Mix	Percentage of variation in strength with reference to base mix				
	Compressive strength			Split tensile strength	Flexural strength
	3 days	7 days	28 days	28 days	28 days
25% sandstone replacement	0.79	0.00	3.43	2.28	10.00
50% sandstone replacement	9.65	5.17	7.60	6.73	13.33
75% sandstone replacement	14.51	6.47	7.52	8.95	16.67
100% sandstone replacement	14.51	7.76	9.09	8.95	20.00

The percentage of increase in compressive strength is a maximum of 9.09%, in split tensile strength 8.95% and in flexural strength 20.0%. The increase in compressive and tensile strength is not very significant, but it is higher than the river sand mixed concrete strength. So, replacing river sand with sandstone is better as it saves river sand which is a natural resources and on the other hand utilization of sandstone produced as a waste material in mining reduces many environmental problems to mining industry and saves a lot of waste dump land. 100 per cent replacement of sand can be adopted as the complete independence from sand can be achieved as many local governments have banned sand mining in rivers.

4. Conclusions

Based on the experimental investigations carried out to assess the suitability to use sandstone for partial replacement of fine aggregates in concrete, the following conclusions were drawn.

• Sieve analysis results depicted an S-curve conforming as well-graded aggregate for sandstone, which can be a substitute for fine aggregates.

• The fineness modulus of the sandstone obtained as 2.25 and its clearly indicating it is a good replacement for fine aggregate.

• Specific gravity and water absorption are near to the conventional fine aggregate and doesn’t show any negative impact on workability.

• Moisture content denotes that the material is feasible for easy transportation.

• SEM Analysis indicates that there is presence of different oxides and high carbon content in sandstone. But there are no harmful elements such as sulphur and calcium.

• Workability of the concrete increased with increasing in percentage replacement of fine aggregate. For all the cases true slump was observed.

• 25% replacement with sandstone didn’t encounter much variation in strength when compared to base mix. But replacement of 50% and 75% rendered a very high early strength to base mix. Even the 100% replacement was slightly greater than 75% in terms of early strength.

• Compressive strength of concrete cubes increased with the increase in percentage replacement of fine aggregate for 3, 7 and 28 days. The maximum increase was in 28 days compressive strength with 100% sandstone. Maximum increases was 9.09%.

• Split tensile strength of concrete was increased with increase in percentage of replacement of fine aggregate with sandstone. The maximum split tensile strength was observed at fine aggregate replaced with 100% sandstone. Maximum increases was 8.95%

• Flexural Strength of concrete was increased with increase in percentage of replacement of fine aggregate with sandstone. The maximum flexural strength was observed at fine aggregate replaced with 100% sandstone and the maximum increase was 20%.

• Based on the above results, it can be concluded that fine aggregates in concrete can be replaced with sandstone which is a waste rock in coal mines, without compromising on any strength aspect. In fact utilization of mine waste in concrete reduces a lot of environmental problems like dust pollution, erosion, loss of vegetation on surrounding areas, etc.

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