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Use of Gold Mine Tailings in Production of Concrete-A Feasibility Study

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Abstract: River sand is becoming scarce and meeting the demand of fine aggregates in the construction industry is becoming a challenging task. In this investigation an attempt is made to utilise gold mine tailings as a partial substitute for river sand in producing concrete. River sand was replaced with 10%, 20% and 30% gold mine tailings and the resulting fine aggregates were used in concrete mix. Mix proportions for M25 concrete were obtained for five mixes as per guidelines given in IS: 10262-2009. Workability, compressive strength, splitting tensile strength and flexural strength are reported. The strengths were obtained at the ages of 7, 14 and 28 days. Compressive, splitting tensile and flexural strengths increased marginally for 10% and 20% replacements. There was slight decrease in the corresponding strength at 30% replacement. Good correlation was observed between compressive strength, splitting tensile strength and flexural strength. This investigation proves that gold mine tailings can be used as a partial substitute for river sand in preparing concrete.

Keywords: *Gold mine tailings, workability, compressive strength, splitting tensile strength, flexural strength*

1. Introduction

Gold mine tailings are one of the primary waste products of mining operations. They comprise of fine grained particles of the parent rock from which the ore is extracted. The characteristics of tailings depend upon the composition of parent rock. The disposal of this material is a major environmental problem for the mining industry.

It is emphasized that industrial and mine wastes can be used to develop sustainable alternative building technologies (1). Amit Rai and Rao (2) have discussed about the potential of utilising industrial / mining rejects and tailings as building materials. They have classified them into three groups and gold mine tailings comes under Group –III, which has the potential of being used as fine aggregate in concrete. Among the 960 million tons of solid waste generated annually in India, nearly 290 million tons are inorganic wastes of industrial and mining sectors (3). Investigation on grain size distribution of gold mine tailings obtained from different sources revealed that the gold mine tailings comprised mainly of fine sand (4, 5, and 6).

The gold mining industry at Hutti village in Raichur district of Karnataka, India is producing abundant quantity of tailings which are unutilised for several years. There is no vegetation on dumps, which leads to release of fine particles into the atmosphere due to wind erosion. This causes air pollution in the area. The tailings have affected the landscape and topography of the area as well. Hence, it is essential to find some way to use the gold mine tailings.

This study is initiated to assess the suitability of gold mine tailings as partial substitute for fine aggregate in concrete. The evaluation was based on parameters such as gradation results, workability, compressive strength, flexural strength and splitting tensile strength. A detailed research on durability studies on concrete prepared with gold mine tailings as partial substitute for fine aggregates will be required before the commercial production.

2. Scope of Present Study

In this study, concrete of M25 grade was obtained and the mixtures were modified by partially replacing river sand with gold mine tailings. The properties of concrete in the fresh and hardened state examined are workability and strength respectively. The workability of concrete mixtures was evaluated in terms of slump and compaction factor tests. The strength of concrete was evaluated in terms of compressive, flexural and splitting tensile strength.

3. Collection of Samples

The gold mine tailings were collected from the dumps of Hutti gold mines, Karnataka, after removing the grass and other weeds from the top surface.

4. Material Properties

4.1 Gold Mine Tailings

The suitability of the material was determined by analysing particle size distribution, specific gravity and chemical composition. The particle size distribution for river sand and gold mine tailings was evaluated as per IS: 2386 (part-II) -1963(7).The fraction of the materials passing through 75 micron sieve was analysed for particle size distribution through Hydrometer analysis .The grading pattern for river sand and gold mine tailings is shown in Figure 1. It can be observed from figure 1, that river sand conforms to Zone – II as per IS: 383-2009 (8) and gold mine tailing is very fine material. The chemical compositions of gold mine tailings were evaluated and are shown in Table 1.

4.2 Fine Aggregates

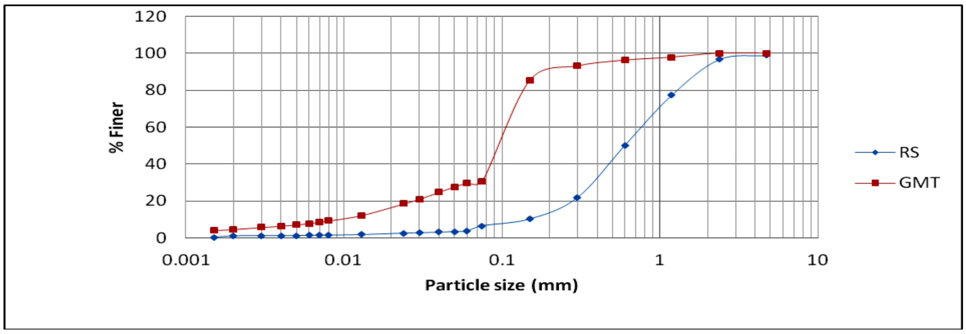
Natural river sand is used as fine aggregates. The properties of fine aggregates are determined by conducting tests as per IS: 2386 (part-1). The particle size distribution curve is shown in Figure 1.

4.3 Coarse Aggregates

Crushed granite jelly obtained from machine crusher is used as coarse aggregate. The aggregate passing through 20mm and retained on 4.75mm is used. Coarse aggregates conform to ssd condition.

4.4 Superplasticiser

In the present investigation, CONPLAST SP 430 super plasticising admixtures is used, which complies with IS: 9103-1979. Conplast SP430is base on sulphonated naphthalene polymers and is applied as a brown liquid instantly dispersible in water. Conplast SP 430 has been specially formulated to give high water reduction up to 25% without loss of workability (9).



RS: River sand, GMT: Gold mine tailings

***Figure 1** Particle size distribution curves for River sand and Gold mine tailings*

***Table1:** Chemical composition of gold mine tailings*

Parameters		Result
Loss on ignition	%	1.08
Calcium as CaO	%	6.10
Magnesium as MgO	%	3.68
Iron as Fe_2O_3	%	6.70
Aluminium as Al_2O_3	%	3.85
Sodium as Na_2O	%	0.078
Potassium as K_2O	%	0.285
Copper as CuO	%	0.010
Manganese as MnO	%	0.077
Parameters		**Result**
Zinc as ZnO	%	0.011
Nickel as NiO	%	0.006
Chromium as Cr_2O_3	%	0.008
Lead as PbO	%	0.007
Silica as SiO_2	%	**71.6**
Chloride as Cl	%	0.070
Sulphate as SO_4	%	0.036
Cyanide as CN	mg/kg	BDL* (D.L.1.0)

**BDL: Below Detection Limit*

4.5 Cement

OPC conforming to IS: 8112-1989 (10) is used. The tests are carried out according to codal provisions.

The experimental programme was broadly divided into four stages, namely

a) Sieve analysis
b) Evolving mix proportions
c) Workability studies and
d) Strength studies

5.1 Sieve Analysis

The main objective of the investigation was to partially replace river sand with gold mine tailings and study the behaviour of concrete in the fresh and hardened state. To get a mixture of river sand and gold mine tailings, river sand was replaced with 10%, 20% and 30% gold mine tailings based on their loose bulk density ratios. The resulting particle size distribution curves are shown in Figure 2. The gradation results are shown in Table 2.

5.2 Mix Proportions

Water cement ratio is an important factor in the process of mix proportioning. Primary requirement of good concrete is satisfactory compressive strength in its hardened state. Many of the desirable properties like durability, impermeability and abrasion resistance is highly influenced by the strength of concrete. The strength can be considered to be solely dependent on water cement ratio for low and medium strength concrete mixes. Workability of concrete varies with water cement ratio and quantity of cementitious material (11, 12). In this investigation, Mix proportions for M25 concrete were obtained as per the guidelines given in IS: 10262-2009(13). The proportions for concrete containing river sand, gold mine tailings and their combinations with water cement ratio and percentage of Superplasticiser is shown in Table 3.

5.3 Workability Studies

Mixing of concrete was done by hand loaded laboratory batch mixer. The ingredients are weighed and batched as per mix proportions adopted. Each batch of concrete was tested for workability in terms of compaction factor and slump immediately after mixing and the results are presented in Table 4.

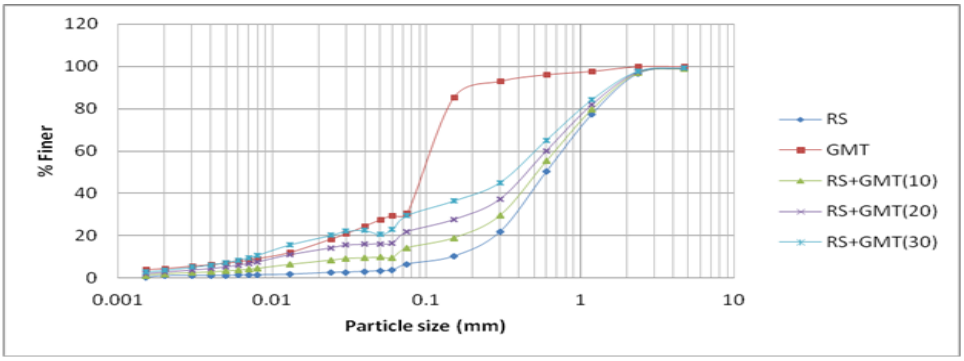


Figure2. *Particle size distribution curves for replacement of river sand with gold mine tailings*

Table 2: *Gradation results for river sand, gold mine tailings and their combinations*

Sand type	Mix Designation	FM	>4.75mm	Coarse (4.75-2.36)	Medium (2.36-0.425)	Fine (0.425-0.075)	Silt (0.075-0.002)	Clay (<0.002)
RS	RS	2.45	1.03	2.3	65.48	24.61	5.52	1.06
GMT	GMT	0.28	0	0	6.16	63.28	25.89	4.67
RS+GMT(0.9:0.1)	RS+GMT(10)	2.23	0.93	2.07	58.97	23.77	12.3	1.96
RS+GMT(0.8:0.2)	RS+GMT(20)	2.01	0.82	1.84	52.47	22.94	19.06	2.87
RS+GMT(0.7:0.3)	RS+GMT(30)	1.79	0.72	1.61	41.96	26.1	25.84	3.77

FM: *Fineness modulus*

Table 3: *Mix proportions for river sand, gold mine tailings and their combinations*

Mix designation	Proportion per m^3 of concrete						Superplasticiser (%)
	Cement (kg/m^3)	Fine aggregates (kg/m^3) RS	Fine aggregates (kg/m^3) GMT	Coarse aggregates (kg/m^3)	Water (kg/m^3)	Water cement ratio	
RS	437.8	657.0	-	1129.7	197	0.45	0.5
GMT	328.3	-	749.0	1187.5	197	0.6	2.5
RS+GMT(10)	437.8	598.53	58.47	1129.7	197	0.45	0.5
RS+GMT(20)	437.8	540.05	116.95	1129.7	197	0.45	0.5
RS+GMT(30)	437.8	481.58	175.42	1129.9	197	0.45	0.5

Table 4: *Workability results*

Mix designation	Compaction factor	Slump (mm)
RS	0.91	84.33
GMT	0.70	16.33
RS+GMT(10)	0.91	63.6
RS+GMT(20)	0.85	44.33
RS+GMT(30)	0.77	22.6

5.4 Strength Studies

5.4.1 Compressive Strength

Standard steel cube moulds of 150mm size were used for casting concrete cubes. The cubes were compacted in three layers using needle vibrator available in the laboratory. Nine concrete cubes were casted for each mix. A total of forty five concrete cubes were casted. Cubes were immersed in water for curing till the date of testing. The specimens were prepared as per IS: 516-1989 (14) and tested for uniaxial compressive strength at 7, 14 and 28 days. The results obtained are the average of three specimens tested and the results are presented in Table 5.

Table 5: *Compressive strength with age*

Mix designation	Compressive strength (MPa) 7 days	14 days	28 days
RS	30.35	39.69	48.00
GMT	6.80	7.33	8.85

RS+GMT(10)	29.10	40.67	51.55
RS+GMT(20)	28.50	37.92	50.36
RS+GMT(30)	26.56	35.07	45.48

5.4.2 Splitting tensile strength

Standard steel cylindrical moulds of 100mm diameter and 200mm length were used for casting cylinders. Nine cylinders were casted for each mix. A total of forty five cylinders were casted. The specimens were prepared as per IS: 516-1989 and tested for splitting tensile strength at 7, 14 and 28 days. The results obtained are the average of three specimens tested and the results are presented in Table 6.

Table 6: *Splitting tensile strength with age*

Mix designation	Splitting tensile strength (MPa)		
	7 days	14 days	28 days
RS	3.92	4.71	4.97
GMT	1.66	2.06	2.86
RS+GMT(10)	3.41	5.09	5.70
RS+GMT(20)	4.50	5.57	6.02
RS+GMT(30)	3.07	3.92	4.49

5.4.3 Flexural strength

Standard steel beam moulds of section 100mm by 100mm and length 500mm were used for casting beams. Nine beams were casted for each mix. A total of forty five beams were casted. The specimens were prepared as per IS: 516-1989 and tested for flexural strength at 7, 14 and 28 days. The results obtained are the average of three specimens tested and the results are presented in Table 7.

Table 7: *Flexural strength with age*

Mix designation	Flexural strength (MPa)		
	7 days	14 days	28 days
RS	5.2	5.6	6.0
GMT	2.8	3.2	4.0
RS+GMT(10)	4.0	6.4	7.6
RS+GMT(20)	5.2	6.0	8.4
RS+GMT(30)	3.6	4.8	5.8

6. Results and Discussions

6.1 Sieve Analysis

About 70% of gold mine tailings are coarser than 75 micron size and 63% of this material belongs to fine sand category. With partial replacement of river sand with gold mine tailings, the fineness modulus of the resulting fine aggregates reduces from 2.45 to 1.79. However, for 30% replacement level, the resulting fine aggregates contain around 70% coarse, medium and fine sand. But the percentage of silt and clay remain same as that in gold mine tailings. The gradation of river sand and gold mine tailings can be altered with appropriate fraction of crushed rock/manufactured sand to make it coarser. With this the percentage of silt and clay in the resulting fine aggregates can be reduced. Chemical composition of gold mine tailings shows that the major constituent is silica and its presence adds to the inert property of resulting fine aggregates.

6.2 Compressive Strength

The control mix attains a compressive strength of 48 MPa at 28 days, which is more than the target strength of 31.6MPa. This may be due to the laboratory conditions and good degree of supervision. Due to large surface area of gold mine tailings, water cement ratio of 0.45 could not be maintained. Hence, water cement ratio had to be increased to 0.6 and with 2.5% Superplasticiser, a reasonably workable concrete could be prepared with gold mine tailings alone as fine aggregates. The target compressive strength could not be achieved, instead the cubes failed at 8.85 MPa after curing for 28 days. This may be due to the increase in water cement ratio and presence of large amount of fines in fine aggregates.

At ten percent replacement level, there is no much variation in strength development when compared to control mix. In case of control mix there is 63% strength development at 7 days and the same is 56% for ten percent replacement level. At 28 days, the compressive strength increases by 7.4%. This increase in strength, even though no appreciable, it may be due to the presence of CaO (6.1%) in gold mine tailings, which might have contributed to the hydration process. In case of 20% replacement also the same trend is observed and the increase in compressive strength at 28 days is 4.9%. At 30% replacement, the 28 days compressive strength decreases by 5.25%. This may be due to the presence of more fines content. However, even at 30% replacement level, a compressive strength of 45.48 MPa could be achieved. The variation in compressive strength with age is shown in Figure 3.

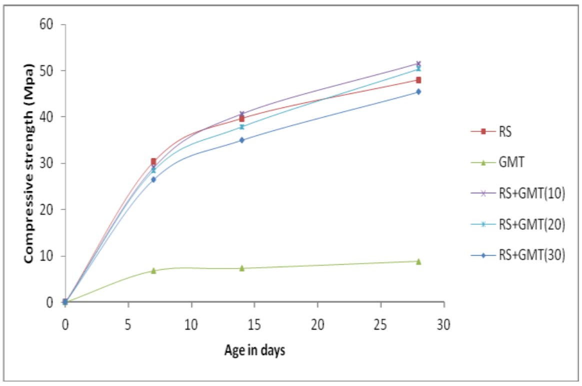


Figure 3 *Variation of compressive strength with age*

6.3 Splitting Tensile Strength

The control mix attains a splitting tensile strength of 4.97 MPa at 28 days which is 10.4% of the 28 days compressive strength. At ten and twenty percent replacement levels, the splitting tensile strength increases by 14% and 21% respectively. Whereas at 30% replacement level, the splitting tensile strength decreases by 9.6%.This behaviour is same as that of compressive strength. The rate of gain of strength for control mix at seven days is 79% and that in case of ten, twenty and thirty percent replacements, the value is 60%, 75% and 68% respectively. The variation of splitting tensile strength with age is shown in Figure 4. The variation of splitting tensile strength with compressive strength for all concrete mixes is shown in Figure 5. It is observed that the correlation is not exactly linear. However the values are comparable.

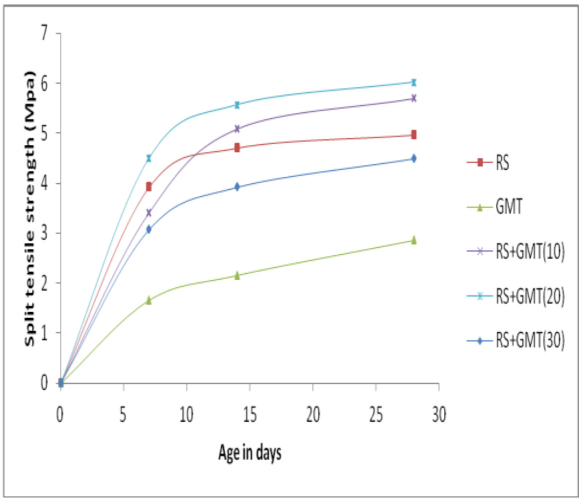


Figure 4 *Variation of splitting tensile strength with age*

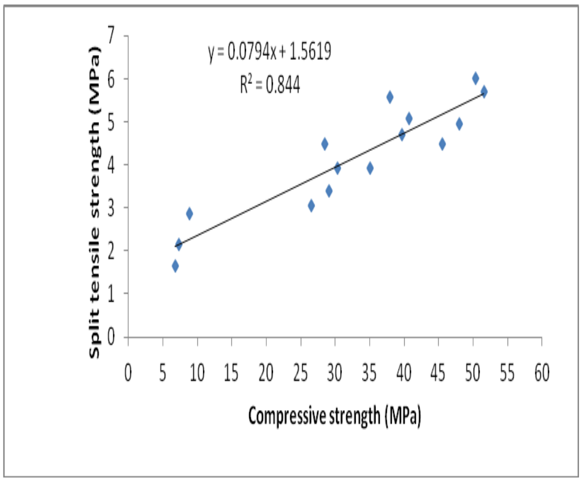


Figure 5 *Splitting tensile strength versus compressive strength*

6.4 Flexural Strength

The flexural strength of control mix is 6 MPa which is 12.5% of the 28 days compressive strength. Like compressive strength and splitting tensile strength, the flexural strength at 28 days marginally increased for ten and twenty percent replacements. However, at thirty percent replacement, the flexural strength decreased marginally. The variation of flexural strength with age is shown in Figure 6. The variation of flexural strength with compressive strength is shown Figure 7.

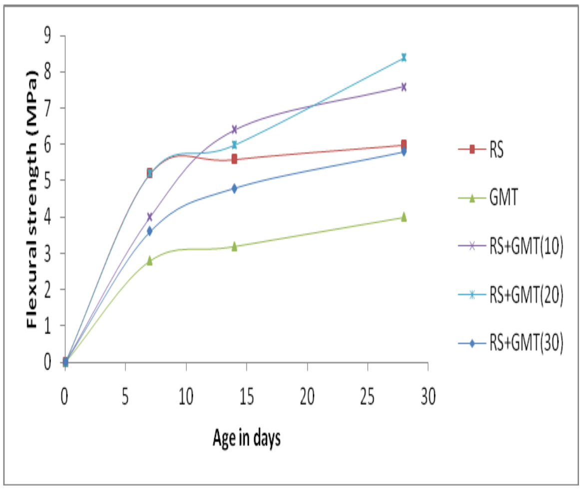


Figure 6 *Variation of flexural strength with age*

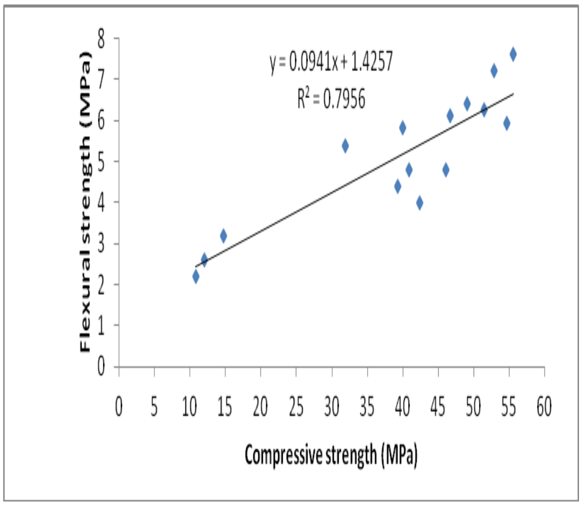


Figure 7 *Flexural strength versus compressive strength*

7. Conclusion

1) Gold mine tailings contain 63% fine sand fraction. Due to partial replacement of river sand with gold mine tailings, the fine sand fraction in the resulting fine aggregate gets reduced. However, at 30% replacement levels the silt and clay content of the resulting fine aggregate is approximately the same as that of gold mine tailings.
2) The gradation of river sand and gold mine tailings can be altered by reconstituting with appropriate fraction of crushed rock/ manufactured sand so that the resulting fine aggregate obtained after partial replacement will satisfy the grading limits.
3) The compressive strength of concrete containing gold mine tailings alone as fine aggregate is 18% of the control mix, which is due to higher water content and also due to presence of higher percentage of fine sand.
4) Concrete of slightly higher compressive strength compared to control mix can be obtained for 10% and 20% replacement of the river sand with gold

mine tailings. Even at 30% replacement, a concrete of compressive strength 45MPa can be achieved.

5) Replacement of RS with gold mine tailings does not affect the rate of gaining strength. For all the three replacement levels, seven days strength achieved is around 56% of the 28 days compressive strength. This is similar to the behaviour of control mix. Hence, the addition of gold mine tailings does not affect the hydration process.
6) The behaviour of concrete under tension is similar to its behaviour under compression. There is a marginal increase in tensile strength for 10% and 20% replacement, whereas for 30% replacement the tensile strength decreases marginally.
7) There is a good correlation between the compressive and tensile strengths for all the three replacement levels.

8. Acknowledgement

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