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EFFECT OF SAND REPLACEMENT BY MILL SCALE ON THE PROPERTIES OF CONCRETE

Anupam Singhal[1], Dipendu Bhunia[1], Bartik Pandel[2,*]
[1]Assistant Professor, Civil Engineering Department,
Birla Institute of Technology and Science, Pilani, India
[2]Undergraduate Student, Civil Engineering Department,
Birla Institute of Technology and Science, Pilani, India

Abstract
Concrete is the most widely used construction material in the world. This popularity of concrete carries with it an immense environmental cost. Billions of tons of natural materials are mined and processed each year to be used in concrete, which leaves a substantial mark on the environment. Efforts to use suitable recycled materials as substitutes for concrete aggregate are gaining in importance, such as recycled concrete aggregate, post-consumer glass, tires, etc. But one waste material which has not been extensively tested yet is mill scale. Mill scale is a flaky hazardous solid waste formed on the steel's surface during the steel manufacturing processes. This work aims to evaluate the use of mill scale in Portland cement concrete, as a replacement for natural fine aggregates. Cement mortars with mix proportioning 1:3 were prepared varying the mill scale content of fine aggregate form 0% to 100%, for determination of compressive and tensile strength. The water/cement ratio used was 0.5 for all mix proportions. The compressive strength at different proportions did not give a general trend and two peaks were obtained at 60% replacement and 100% replacement. Maximum tensile strength was observed at 60% replacement of standard sand. A mix design was also done for M35 grade of concrete by the IS method. OPC of 43 grade was selected and sand replacement was done with mill scale varying from 0% to 80% with a suitable water cement ratio of 0.40. The compressive strength was measured after 28 days of completion of curing. Maximum strength was obtained for 40% sand replacement. Moreover, concrete with mill scale has demanded greater water content to maintain the workability.

1. Introduction
Globally, over 10 billion tons of concrete is manufactured every year. Such volumes require enormous amounts of natural resources for aggregate and cement production. The concrete industry can improve its compliance with environmental sustainability by increased reliance on recycled materials. Since aggregates usually account for 70-80% of the concrete volume and play a significant role in defining concrete properties such as workability, strength and durability, an effective recycling strategy to incorporate waste into concrete will lessen the demand for virgin materials.
In the last 15 years, it has become evident that the availability of good quality natural sand is diminishing. Existing natural deposits are being exhausted at a tremendous rate and new deposits are located either underground or very close to already built up areas or too far away from the regions where it is needed. Environmental concerns are also being raised against uncontrolled extraction of natural sand. The arguments are mostly related to protecting riverbeds against erosion and the importance of having natural sand as a filter for groundwater. With natural sand deposits the world over drying up, there is a dire need for a product that can replace natural sand, at least partially [1].

With the dearth of space for land filling and due to its ever increasing cost, waste utilization has become an attractive alternative to disposal. There is a growing interest in using waste materials as alternative aggregate materials and significant research has been done on the use of foundry sand, fly ash, blast furnace slag, fiber glass, waste plastics, rubber waste etc. This paper emphasizes on the use of mill scale to be substituted for natural sand. The work included in this paper comprises only mechanical properties of the developed material and a lot more experiments are yet to be performed.

2. Literature Review

In several iron and steel making processes, about 500 kg/ton of solid wastes are generated, one of these wastes is mill scale which represents about 2% of the steel produced [2]. Mill scale is a layer of iron oxide which forms on ferrous materials during continuous casting, reheating and hot rolling operations. It contains both iron in elemental form and three other types of iron oxides: wustite (FeO), hematite (Fe_2O_3) and magnetite (Fe_3O_4). The iron content is typically around 70% with traces of non-ferrous metals and alkaline compounds. Mill scale is formed by flaky particles of a size of generally less than 5 mm. The size distribution depends on the point in the process where the mill scale is generated. Approximately, 90% of mill scale is directly recycled within steelmaking industry and small amounts are used for ferroalloys, in cement plants and in the petrochemical industries. However, finer mill scale which is heavily contaminated with oils, ends up in landfills [3]. This residue is classified as hazardous waste by the Environmental Protection Agency.

Worldwide, about 13.5 million tons of mill scale are generated annually [2]. Some waste from steelmaking operations and metallurgy have established widespread use in the construction sector, for example, granulated slag from the production of pig iron is used as aggregates in concrete. Many investigations have shown that slag aggregate concretes achieve higher values of compressive strength, tensile strength, flexural strength and modulus of elasticity, compared to natural aggregate concretes [4, 5].

However, very limited literature is available on the subject topic of this paper. Pradip et al. (1990) [6] carried out research on utilizing steel mill scale in the production of cement mortar. Al-Otaibi (2008) [7] investigated the possibility of recycling steel mill scale in cementitious materials as aggregate, analyzing cement mortars with levels of 0%, 20%, 40%, 50%, 70% and 100% replacement. Values of compressive strength analyzed for all ages (3, 7 and 28 days) increased with the replacement of upto 40% replacement, also with a reduction of drying shrinkage with 70% of mill scale steel. The results of another study conducted by Pereira et al. (2011) [8] on the use of mill scale as fine aggregate in concrete have shown that mill scale demands greater water content to maintain the workability. The results indicated that concretes with water/cement ratios of 0.55 and 0.65 have higher compressive strength and greater water absorption as the mill scale content increase.

This paper presents the findings of a study that investigates the potential for recycling steel mill scale into concrete. The composition of steel mill scale was determined by XRD analysis. For mortar samples, river sand was replaced by 20%, 40%, 60%, 80%and 100% mill scale whereas, for concrete cubes, the replacement was restricted to only 80% as the weight of concrete was increasing at a very fast rate and complete sand replacement did not seem practical. Compressive strength and tensile strength were measured for different specimens of the mortar and concrete samples. The results are promising and encourage further study in applications in concrete, brick and block manufacturing.

3. Materials

3.1 Cement

Ordinary Portland cement of 43 grade compliant with IS 8112:1989 specifications was used.

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3.2 Indian Standard Sand- Ennore.

The aggregate used was the standard sand compliant with IS: 2116-1980 specifications which is widely used for mortar testing. The sand was uniformly graded with grain size lying between 1-2mm. The properties of the sand are given in Table 1.

Table 1. Properties of Ennore Sand

Physical Properties	
Colour	Grayish White
Specific Gravity	2.64
W. Absorption in 24 hours	0.80%
Shape of Grains	Sub Angular
Chemical Properties	
SiO_2	99.30%
Al_2O_3	-
Fe_2O_3	0.10%
CaO	-
Loss on Ignition	-

3.3 Mill scale

Mill scale was obtained from a firm located in Vishwakarma Industrial Area, Jaipur. As the particles were very flaky and greater than 4.75mm, the material was ground in Los Angeles machine for 500 revolutions at a speed of 33 revolutions per minute. The bulk density as determined by the IS: 2386 (Part III)-1963 method was found to be 5.6 g/cm^3. Particle size distribution was done for mill scale and standard sand as per IS: 2386 (Part I)-1963 specifications which is shown in Figure 2.

Figure 1. Mill scale after grinding in Los Angeles machine

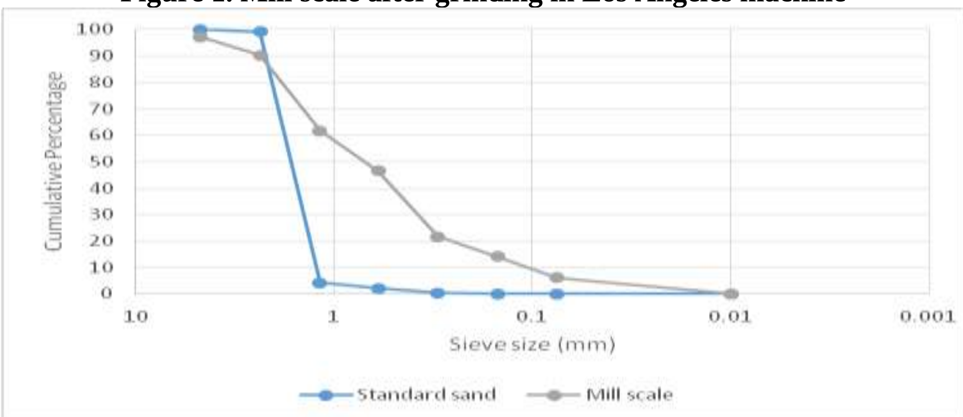

Figure 2. Particle size distribution curve for mill scale and standard sand

The constituent phase analysis of mill scale was performed by X-ray diffraction analysis to determine the composition. The graph is shown in Figure 3. The analysis shows that mill scale is mainly composed of magnetite (Fe_3O_4), hematite (Fe_2O_3) and wustite (FeO).

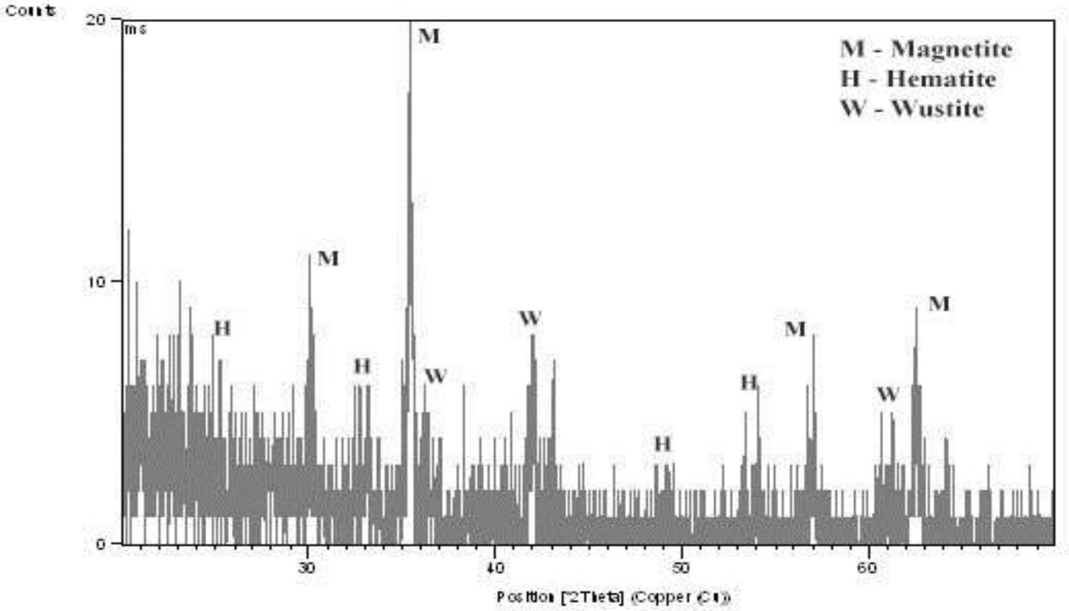

Figure 3. X-Ray Diffraction analysis of raw mill scale

4. Methodology

4.1 Preparation of mortar cubes and briquettes

To prepare the mortar cubes, cement and fine aggregate were mixed in the ratio of 1:3 with a water/cement ratio of 0.50. A high value of 0.50 was chosen as previous studies have shown that workability reduces with increased proportion of mill scale in mortar. Standard sand was replaced by mill scale by weight with levels of mill scale as 0%, 20%, 40%, 60%, 80% and 100% (Table 2). Considering the difference of specific mass of standard sand and steel mill scale, the correction for weight of material was performed for every composition to keep the volume same. Moulds of size 70.6mm*70.6mm*70.6 mm were used for casting of mortar cubes. For casting tensile test samples, standard briquette moulds were used.

Table 2. Composition of mortar samples

Sample	Water (g)	Cement (g)	Mill scale (g)	Sand (g)
Control	400	800	0	2400 (100%)
1	400	800	480 (20%)	1920 (80%)
2	400	800	960 (40%)	1440 (60%)
3	400	800	1440 (60%)	960 (40%)
4	400	800	1920 (80%)	480 (20%)
Full replacement	400	800	2400 (100%)	0

4.2 Preparation of concrete cubes

For the preparation of concrete cubes mould size of 150mm*150mm*150mm was used and for every composition, 6 cubes were cast. Proper mix design was done for M35 concrete at a water cement ratio of 0.35 as per IS guidelines but the water content had to be increased later to 0.40 as the water was found to be insufficient while mixing the concrete. 80 ml superplasticizer was used to provide

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sufficient workability. Sand was replaced by mill scale at levels of 0%, 20%, 40%, 60% and 80% (shown in Table 3).

Table 3. Composition for different samples of concrete cubes

Sample	Water (kg)	Cement (kg)	10mm aggregate (kg)	20mm aggregate (kg)	Local Sand (kg)	Mill scale (kg)	Admixture (ml)
Control	5.526	13.68	11.052	15.768	12.672	0	80
1	5.526	13.68	11.052	15.768	10.138	2.534	80
2	5.526	13.68	11.052	15.768	7.603	5.059	80
3	5.526	13.68	11.052	15.768	5.069	7.603	80
4	5.526	13.68	11.052	15.768	2.534	10.138	80

5. Results

5.1 Density of mortar cubes

The density of mortar specimens was determined by diving the average weight of three cubes by the volume of the cubes. The bulk density of mortar samples is given in Table 4, graphical curve for the same is shown in Figure 4.

Table 4. Density of mortar samples containing varying percentage of mill scale replacement

Sample	Mill scale (%)	Density of cubes (kg/m^3)
Control	0	2459.0
1	20	2584.9
2	40	2730.6
3	60	3000.9
4	80	3136.7
Full replacement	100	3399.8

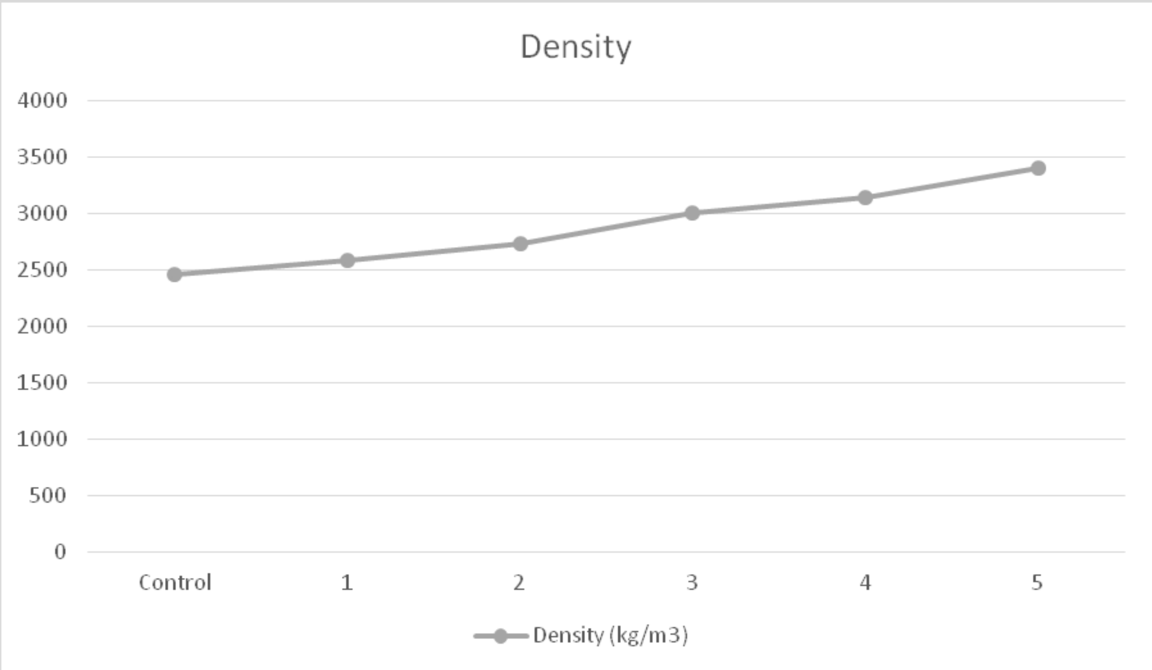

Figure 4. Curve showing variation of density of different mortar samples

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5.2 Compression test on mortar cubes

The compression strength tests were performed by procedures established in IS: 2250-1981 at 7 days age, in electrohydraulic press with capacity 150 tons. The results of the compression test for various compositions after 7 days curing are tabulated in Table 5. A graph for the same has been shown in Figure 5.

Table 5. Compressive strength of mortar samples after 7 days curing

Sample	Mill scale (%)	7 days compressive strength (MPa)
Control	0	27.0
1	20	26.5
2	40	23.67
3	60	29.67
4	80	28.33
Full replacement	100	35

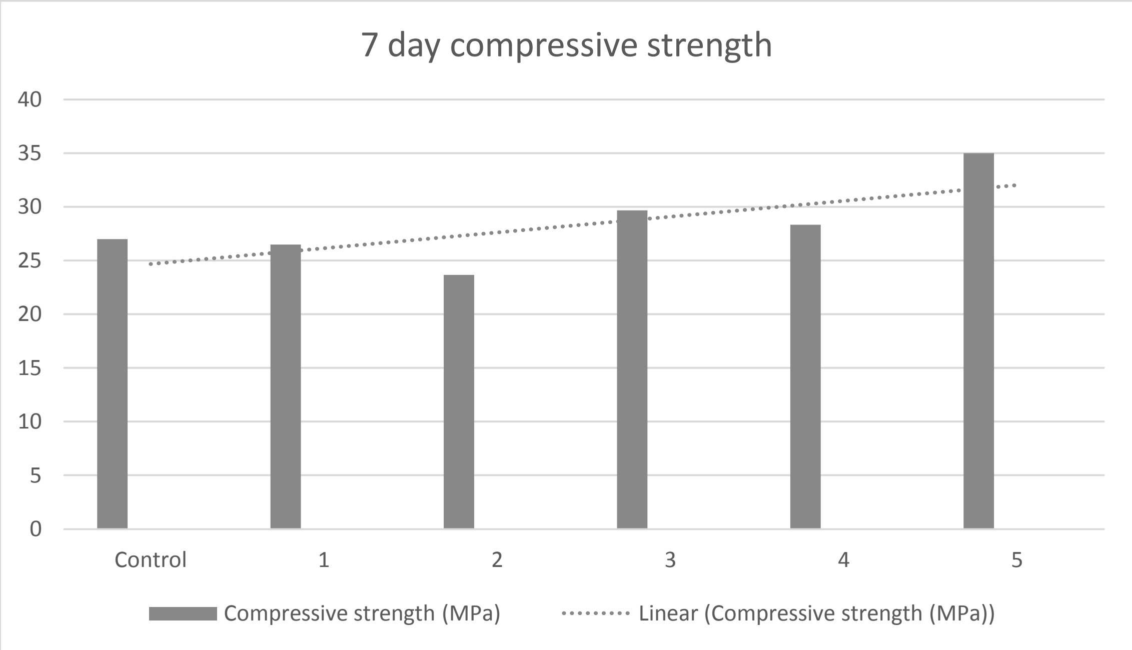

Figure 5. Graph showing compressive strength of mortar samples after 7 days curing

5.3 Tensile test on mortar samples

The tensile strength test was performed on standard briquette sized mortar samples after 7 days of curing on cement tensile testing machine. The tensile strength of different mortar compositions is presented in Table 6, graph for the same is shown in Figure 6.

Table 6. Tensile strength of mortar samples after 7 days curing

Sample	Mill scale (%)	7 days tensile strength (N)
Control	0	320
1	20	286
2	40	364.67
3	60	378
4	80	458.67
Full replacement	100	394.67

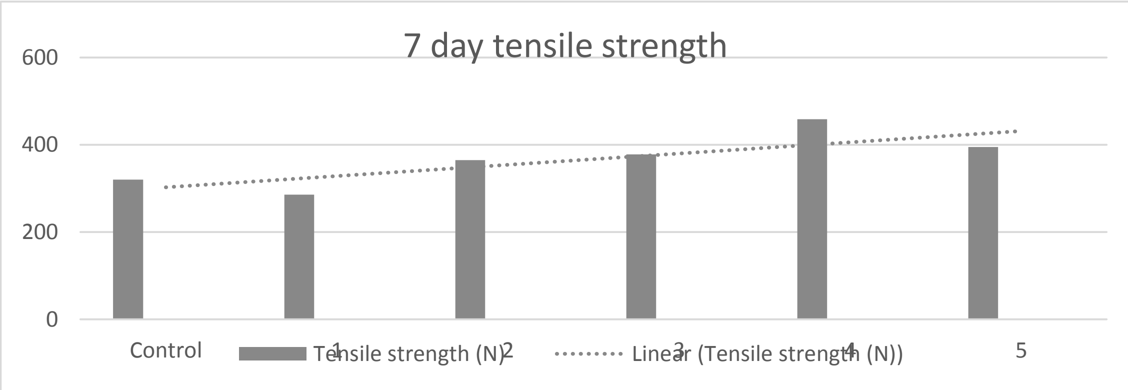

Figure 6. Graph showing tensile strength variation for different mortar samples

5.4 Compression test on concrete cubes

The compression strength tests were performed by procedures established in IS:516 (1959) at 28 days age, in electrohydraulic press with capacity 150 tons. The results of the compression test for various compositions after 28 days curing are tabulated in Table 7. A graph for the same has been shown in Figure 7.

Table 7. Compressive strength of concrete samples after 28 days curing

Sample	**Mill scale (%)**	**28 days compressive strength (MPa)**
Control	0	34.8
1	20	35.7
2	40	37.0
3	60	31.7
4	80	33.5

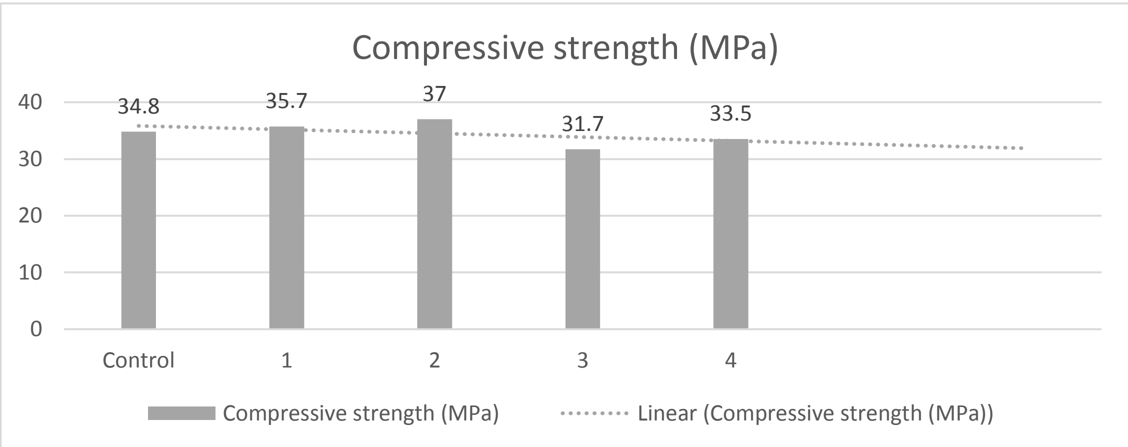

Figure 7. Graph showing compressive strength of concrete samples after 28 days curing

6. Discussion and Conclusions

As shown by the graphs, the overall trend in case of both compressive and tensile strength is positive i.e. the strength of mortar samples is increasing with substitution of mill scale for sand. Except for 20 % replacement all the other compositions have shown higher compressive and tensile strength than the control sample (0% sand replacement). In the case of concrete samples, maximum compressive strength was observed for 40% replacement beyond which the strength starts to decline.

However, the bulk density of mortar samples increased considerably with sand replacement by mill scale which is obvious as the specific gravity of mill scale is much greater than the specific gravity of sand. It was observed that the use of mill scale increased water demand for maintaining the required workability in agreement with the finding of Pereira et al. (2011) [8].
The development of this research showed variation in performance of Portland cement concrete by using mill scale as fine aggregate according with the results. The absence of a particular trend in the strength could be due to orientation of the flakes of mill scale which needs to be further studied by electron microscopy. As the weight of concrete increased substantially due to mill scale addition, investigators can try replacing the cement with fly ash or something lighter in weight to counteract the effect of mill scale addition. To confirm the potential use of mill scale in cement concrete or mortar, additional studies should be performed since the results obtained in the present study indicate the possible influence of contamination by oils and greases on the observed performance.
During different industrial, mining, agricultural and domestic activities, India produces annually about 960 MT of solid wastes as by-products, which pose major environmental and ecological problems besides occupying a large area of land for their storage/disposal [9]. Looking to such huge quantity of wastes as minerals or resources, there is a tremendous scope for recycling and using such solid wastes in construction materials. To effectively utilize these wastes as a raw material, filler, binder and additive in developing alternative building materials, detailed physical-chemical, engineering, thermal, mineralogical and morphological properties of these wastes are to be evaluated and accurate data made available.

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