Significance of processing laterite on strength characteristics of laterized concrete

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Abstract: The boom in infrastructure development has resulted in acute shortage of river sand. To address this issue, it is required to find substitutes for river sand for producing concrete. One among the locally available marginal resource is laterite. In this study, an attempt is made to study the performance of cement concrete using laterite as fine aggregate in replacement levels of 25, 50, 75 and 100% to natural fine aggregates (river sand). Studies were carried out in two stages, initially river sand is replaced with laterite quarry waste (unprocessed laterite), and then it is replaced with the processed laterite. The workability and compressive strength characteristics of concrete are studied. Results indicate that, the decrease in compressive strength of concrete with increase in replacement levels of river sand by unprocessed laterite was more, compared to concrete with processed laterite. However, there is only 7% reduction in strength for laterized concrete with 100% processed laterite compared to control concrete. Microstructure studies were also conducted to understand the morphology of river sand and laterite particles with the cement matrix using scanning electron microscope.

1. Introduction

1.1 General
Concrete has been extensively used as construction material ever since it is introduced in the construction industry. The average annual production is approximately 1 ton of concrete per human being in the world [1]. An important factor that affects the construction industry in developing countries is the cost of construction materials. As prices rise sharply, there is a growing recognition that research must be linked to indigenous materials as substitutes to the construction of functional but affordable housing in rural and urban India. Recent years have seen several studies involving the use of new materials that can substitute conventional materials for concreting. These new materials are carefully chosen for research either because they are available in abundance or, in the case of waste, since they are harmful to the environment. Both the above-mentioned reasons are the main motivation for the current study. Laterite being one among those abundantly available soils in several parts of the world. For decades it has been used for brick production and as a subgrade material for road construction.

1.2 Laterite
Laterite and allied soils are extensively dispersed in the tropical and subtropical regions of Africa, Australia, India, Southeast Asia and South America. In India, they cover a total area of about 248,000 square kilometers. Laterites are especially developed at the top of the Deccan Hills, Madhya Pradesh, East Ghat areas of Orissa, Maharashtra, Karnataka, Kerala and parts of Assam in India [2]. In many parts of India, laterite stone is generally used as building block for construction purposes. There are numerous laterite stone quarries in the Konkan region. During quarrying of the laterite stone,
approximately 25 to 30% of laterite stone debris is generated. It is estimated that approximately 2.83 cubic meters of laterite waste is generated during the excavation of around 11.33 cubic meters of laterite stone. This laterite scrap creates problems in quarries and must be removed for other quarrying works. Towards sustainability, to add value to this waste and using it as a building material is needed [3].

1.3 Laterized concrete
Laterized concrete can be defined as the concrete in which partial or full replacement of river sand by laterite sand [4]. The utilization of laterized concrete as a building material in India has not yet become popular because of the lack of an adequate understanding of its characteristics and its performance. Even though studies on the use of laterite soil in construction have been carried out in countries like Nigeria, Australia, Malaysia, India and some other North African countries, but they are limited to using it as subgrade material in road construction and as building blocks in some places. Some experimental studies on replacement of natural river sand by laterite soil are reported by researchers. No studies have been reported on the processing and characterization of lateritic soil for replacement to natural river sand for producing concrete.

2. Materials
2.1 Cement
The cement used is Ordinary Portland Cement (OPC) of 53 grade that complies with IS: 12269-1987.

2.2 Fine Aggregates
2.2.1 River sand
Clean dry natural river sand obtained from local supplier conforming to IS: 383-1970 is used. The physical properties of fine aggregate are tabulated in table 1.

2.2.2 Laterite
In the present study, laterite is obtained from laterite quarry near Surathkal, Dakshina Kannada District, Karnataka. Physical properties of laterite are as shown in table 1.

| Sl. No | Property | As per IS-code test procedure | Results |
|--------|----------|-------------------------------|---------|
|        |          |                               | River sand | Laterite |
| 1      | Specific gravity | IS: 2386-1963 (Part III) | 2.63     | 2.66     |
| 2      | Bulk density i) Loose | IS: 2386-1963 (Part III) | 1340 kg/m³ | 1300 kg/m³ |
|        | ii) Compact      | IS: 2386-1963 (Part III) | 1535 kg/m³ | 1514 kg/m³ |
| 3      | Moisture content | IS: 2386-1963 (Part III) | Nil      | Nil      |
| 4      | Fineness modulus | IS: 383-1970                 | 2.65     | 3.59     |

Water absorption test is conducted according to IS: 2386 (part III)-1963. Test is conducted for different fine aggregates with different particle sizes as shown in table 2.

| Particle size (mm) | Type of fine aggregates | River sand | Processed laterite fine aggregates | Unprocessed laterite fine aggregates |
|--------------------|-------------------------|------------|-----------------------------------|-------------------------------------|
| 4.75               | 1.0                     | 6.0        | 6.0                               |
| 2.36               | 1.0                     | 6.0        | 6.0                               |
| 1.18               | 1.0                     | 7.0        | 9.5                               |
| 0.60               | 1.5                     | 7.5        | 12.0                              |
| 0.30               | 1.5                     | 8.0        | 15.0                              |
| 0.15               | 2.0                     | 10.0       | 16.5                              |
| Whole mix (zone II)| 1.0                     | 7.0        | 12.0                              |

Water absorption of aggregates plays a significant role controlling the fresh and hardened properties of concrete. From table 2, one can observe that water absorption increases with decrease in particle size for all the type of fine aggregates. Laterite fine aggregates shows higher values of water absorption
compared to river sand, and it is due to the porous nature of laterite aggregates. In particular, unprocessed laterite fine aggregates possess higher values than the processed laterite due to the presence of fine clay sized particles which tend to absorb and hold the water. Grain size distribution of aggregates play a vital role that control the physical and mechanical properties of concrete. Figure 1 shows the grain size distribution of river sand and unprocessed laterite in comparison with the lower and upper limits of zone II. Figure 1 also shows that river sand satisfies the Zone II limits and laterite did not satisfy the Zone II limits, which means that laterite contains coarser particles compare to river sand.

![Figure 1](image1.png)

**Figure 1** Particle size distribution of river sand and unprocessed laterite.

2.3. Chemical composition

Indian standard method of test for soils [IS 2720(part 25);1982] is used for the chemical analysis of laterite samples. Silica (SiO$_2$) was assessed gravimetrically and sesquioxides (Fe$_2$O$_3$ and Al$_2$O$_3$) by volumetric methods. The results are presented in figure 2. Various chemical compounds present in fine aggregates (river sand and laterite) is determined. The chemical composition of laterite fine aggregates reported here agree with other researchers [5].

![Figure 2](image2.png)

**Figure 2** Graphical representation of metallic oxides in different fine aggregates.
2.4 Coarse aggregates
Crushed granite aggregates obtained from the local quarry are used as coarse aggregates. The coarse aggregates used here, was of size 20 mm down and holding 4.75 mm. Physical properties of coarse aggregates satisfies the requirements as per IS-2386 (part III &IV)-1963.

2.5 Water
Water is one of the primary ingredients of concrete, which is necessary for the hydration of cement in concrete. Potable quality water is used.

2.6 Laterized concrete mix design adopted
For concrete, nominal mix of 1:1.5:3 (cement: fine aggregates: coarse aggregates) with water to cement (W/C) ratio of 0.5 is adopted. The concrete was mixed in concrete mixer and poured into cube moulds of size 150 mm. Cubes were given sufficient vibration to achieve necessary compaction. The cubes were de-moulded after 24 hours and cured for 28 days in water. Total of 54 concrete cubes were cast.

3. Experimental Methodology
The experiments are performed in two stages. In the first stage, river sand is replaced by unprocessed laterite in levels of 0, 25, 50, 75 and 100% for performance study of fresh and hardened properties of concrete. In the second stage, river sand is replaced by processed laterite in terms of 0, 25, 50, 75 and 100%. Here processed laterite means, laterite is subjected to processing and it is blended to have the particle size distribution as that of river sand. Unprocessed laterite means, laterite without processing and it has its own particle size distribution.

3.1 Methodology for obtaining processed laterite
Initially waste laterite blocks were collected from the nearby quarry. Then the blocks were crushed into small pieces using crushing equipment and hammer. Crushed laterite is sieved using 4.75 mm sieve. Afterwards, crushed laterite was washed on a wooden frame sieve, having sieve size of 150 microns. Washing is very important step in processing of laterite, because most problematic part in laterite is the fine clay particles present. In the earlier research works they observed the clay ball like formations, which are de-moulded then sun dried. Laterite obtained from the above process is dried laterite. The above process results in decrease in compressive strength of concrete as more amount of water is absorbed by the clay portion of laterite [6]. This can be overcome by washing. Now the obtained laterite is free from the problematic clay fraction, then sun-dried. Laterite obtained from the above process is made to pass through set of IS sieves starting from 4.75 mm to 150 microns’ sieves. Laterite collected from different sieve size is stored in separate bags, so that we can blend sand fractions of any gradation similar to the river sand which is to be replaced.

4. Result and discussions
In this section, the results obtained on laterite based concretes are discussed. The workability of fresh concrete and the variation in compressive strength are discussed in detail.

4.1 Fresh concrete-workability tests
Standard slump cone apparatus was used for measuring slump. 80 mm slump was observed for control concrete containing 100% river sand. During the slump tests, it was found that the workability of fresh concrete made with 100% replacement of river sand with unprocessed laterite had slump value reduced to 0 mm. With increase in percentage of laterite in concrete, workability was getting lower. This was due to the higher water absorption (12%) of the unprocessed laterite as compared to the natural fine aggregate (1%) [7]. From table 3, it can be observed that slump value of concrete decreases with increase in replacement to river sand by both the processed and unprocessed laterite fine aggregates. But decrease in slump value for processed laterite based concrete is less compared to unprocessed laterite based concrete. In case of unprocessed laterite based concrete, reduction in slump value is 100% for 100% replacement of river sand. But in case of processed laterite based concrete, reduction in slump is only 38% for 100% replacement of river sand.
Table 3. Slump results for different type of fine aggregates in OPC based concrete

| Sl. No | River sand (%) | Fine aggregate (%) | Processed laterite | Slump (mm) |
|--------|----------------|--------------------|--------------------|------------|
| 1      | 100            | 0                  | -                  | 80         |
| 2      | 75             | 25                 | -                  | 50         |
| 3      | 50             | 50                 | -                  | 30         |
| 4      | 25             | 75                 | -                  | 15         |
| 5      | 0              | 100                | -                  | 0          |
| 6      | 100            | -                  | 0                  | 80         |
| 7      | 75             | -                  | 25                 | 75         |
| 8      | 50             | -                  | 50                 | 65         |
| 9      | 25             | -                  | 75                 | 50         |
| 10     | 0              | -                  | 100                | 50         |

4.2 Compressive strength of laterized concrete with unprocessed laterite

Figures 3 and 4 shows results of compressive strengths of unprocessed laterite based concretes at different curing durations and different replacement levels of river sand by unprocessed laterite. It can be observed that, as laterite content increases, strength is gradually decreasing for both the curing durations. In the case of 7 days of strength for 25, 50, 75 and 100% replacement of river sand, reduction in strength were around 14, 16, 29 and 36% respectively.

![Figure 3](image1.png)

Figure 3 7 days compressive strength (a) and normalized compressive strength (b) of laterized concrete with unprocessed laterite.

28 days of curing for 25, 50, 75 and 100% laterized concrete have shown 6, 10, 23 and 34 % reduction in compressive strengths respectively. Large reduction in strength of laterized concrete may be attributed to the formation of clay lumps in the concrete, which is due to the presence of fine clay particles of unprocessed laterite. These clay lumps make the concrete less brittle which in turn reduces the compressive strength of laterized concrete and also there will be no proper bonding between the coarse aggregates, cement and the clay coated unprocessed laterite.
4.3 Compressive strength of laterized concrete with processed laterite

Figures 5 and 6 represent the compressive strength results for processed laterite based concrete at 7 and 28 days curing respectively. From figures, it was observed that, strength values remain almost same for all replacement levels at both the curing durations. In case of 7 days of strength for 50, 75 and 100% replacement, reduction in strength were around 8, 11 and 16% respectively. But for 25% replacement, there will be 1% increase in strength compared to control concrete at 7 days curing.

For 28 days of curing at 50, 75 and 100% laterized concrete have shown only 2, 1 and 7 % reduction in compressive strength respectively. But for 25% replacement, there will be 2% increase in strength compared to control concrete at 28 days curing. These results are due to the usage of processed laterite, which has similar physical properties as of natural fine aggregates leading to proper binding between the processed laterite aggregates and cement matrix.
Figure 6 28-day compressive strength (a) and normalized compressive strength (b) of laterized concrete with processed laterite.

4.4 Microstructure analysis

Microstructural analysis is adopted to understand the performance of laterized concretes. Scanning Electron Microscope (SEM) is used to study the micro structural arrangement of hydrated cement paste, laterite and river sand aggregate phases. SEM images were studied by taking Back Scattered Electron (BSE) images for morphology study. Figures 7 and 8 presents SEM micrographs of laterized concrete using 100% unprocessed laterite and processed laterite respectively. From figure 7, one can observe the loose and more porous ITZ between the unprocessed laterite and the cement matrix.

Figure 7 SEM micrographs of laterized concrete using 100% unprocessed laterite.

The reason for this loose ITZ, is due to the presence of clay coating on the unprocessed laterite. These porous zones are responsible for decrease in strength of the concrete [8]. From figure 8, denser and less porous ITZ is observed for the laterized concrete with processed laterite. The width of the porous zone in the ITZ ranges between 1-2 μm for laterized concrete with processed laterite, whereas for laterized concrete with unprocessed laterite shows width ranges between 5-8 μm.
Figure 8 SEM micrographs of laterized concrete using 100% processed laterite.

5. Conclusions
1. The workability of concrete mixes with unprocessed laterite are substantially lower compared to those with processed laterite
2. Even the rate of strength loss with increase in replacement levels is higher for those mixes, with unprocessed laterite than with processed laterite.
3. Strength reduction of 34% was observed for 100% unprocessed laterite based concrete whereas only 7% strength reduction for 100% processed laterite based concrete, is observed.

6. References
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