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# Weathering Forms and Properties of Laterite Building Stones Used in Historic Monuments of Western India

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ABSTRACT: Laterite, a world wide occurring weathered rock, is one of the most predominant building stone used in permanent structures along the west coast of India. This paper focuses on characteristics of alteration of laterite building stone used in historic monuments along the west coast of India. Field study was conducted on laterite monuments of international importance in Goa and Kerala to identify the locations of decay and to classify them based on the causes. Engineering properties of fresh laterite stone samples from local quarries of Malabar region, Kerala were also determined on a scientific basis. It is seen that decay processes rarely operate in isolation; they are due to a combination of several causes. Dampness was identified as a major factor involved in weathering of laterite, hence protection from dampness will prevent deterioration of laterite structures to a large extent. This study suggests a base for the conservation strategies and selection of material for repair of laterite monuments.

## 1 INTRODUCTION

Since prehistoric times, locally available laterite has been used in historic monument construction along the west coast of India. Historic monuments located in this region which includes world heritage group of churches at Goa, prehistoric megaliths of Kerala, maritime forts, palaces, temples, traditional residences and many ancillary structures, were built using laterite. In spite of its wide use in monumental architecture, very little is known about its engineering characteristics and weathering mechanisms. Understanding material properties and weathering mechanisms is highly essential for the sustainable conservation of these monuments. Importance of conservation of heritage monuments is keenly felt by many organizations in India in the recent years. This study will contribute highly for the sustainable protection of laterite monuments of international and national importance.

A few important laterite monuments of national importance are presented based on a study conducted in Goa and Kerala. The weathering nature of laterite stone combined with aggressive tropical and humid environment has resulted in damages to the historic monuments in Kerala and Goa (ASI Kerala 2002; ASI Goa 2002). Deterioration of laterite in monuments was studied and classified based on the cause's field investigations. Field investigations were conducted to study deterioration on laterite monuments. Weathering forms of laterite structures in different environment were identified and classified based on the causes to evolve appropriate strategy for their conservation. Physico- mechanical properties of fresh laterite blocks from popular quarries located in Malabar region were also determined which will be useful for appropriate selection of material for repair and restoration procedures

## 2 LATERITE MONUMENTS

Laterite monuments in UNESCO world heritage list include Angor Watt temple, Cambodia, Churches and associated buildings in Goa, India. Old Goa is an open air museum of imposing churches, convents and monasteries as remnants of a well- flourished community during the 15-16$^{th}$ century. A few of the massive churches are St. Cajetan, St. Catherine, St Augustine and Basilica of Bom Jesus. These churches were built in European models using locally available laterite and details executed with artistic expertise of local craftsmen. Bom Jesus Church, old Goa is an imposing structure in exposed laterite as shown in Fig. 1.

Figure.1 : Basilica of Bom Jesus (15$^{th}$ Cent. A.D.), Old Goa.

### *2.1 Prehistoric megaliths*

Prehistoric megaliths of unique forms made using laterite namely Kodakkallu, Thoppikkallu, menhirs and caves were found located in lateritic zones of Kerala as shown in Fig. 2. These vestiges made using laterite are the earliest remains of human embellishments. They stand as testimony of sound construction practices adopted in laterite in the distant past and the remarkable resistance of the material to weathering.

(a) Umbrella stone (Kodakkallu) (b) Entrance to a Megalithic cave

Figure. 2 : Prehistoric megaliths of Kerala ( 2$^{nd}$ Cent. B.C. to 1$^{st}$ Cent. A.D.).

### *2.2 Traditional temples of Kerala*

The rich and unique architecture feature of exposed laterite masonry is seen in temples and traditional residences of Malabar region. The workability of laterite combined with the technical skills of Stapathis (master craftsmen) is reflected in decorative and molded basements (adhistana) of temples (as shown in Fig. 3). Laterite was also used for variety of other ancillary applications like pavements, steps, and special structures like arches and vaults.

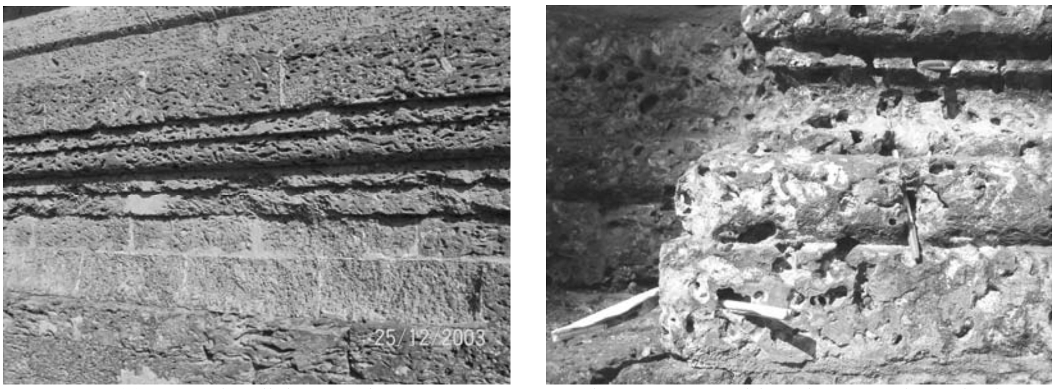
Figure.3 : Typical traditional temple in Kerala built using exposed laterite masonry.

## 3 FIELD STUDY: WEATHERING FORMS ON LATERITE MONUMENTS

Field study of monuments provides first hand information on deterioration types and an insight into their causes. The locations of decay were identified and classified based on the cause and nature of decay into four categories, namely physical disintegration, biological attack, deterioration due to salt attack and human intervention (Fitzner and Heinrichs 2004, Smith and Curran 2003). The representative weathering forms of each category are described below. These decay forms are typical of several monuments.

### *3.1 Loss of material*

Physical damages caused due to lashing rain, wetting and drying cycles and thermal changes. Loss of cohesion of minerals causes granular disintegration and surface loss of material. Disintegration of laterite mainly in exposed areas of basement was mainly due to the growth of salt crystals. The soft clayey part within the matrix is washed off by means of rain and wind resulting in honey combing.




(a) Granular disintegration (b) Honey combing due to action of rain

Figure 4 : Damage due to loss of material.

### *3.2 Bio-degradation*

Damp surface of laterite attracts dust, dirt, insects, termites and other microorganisms. If this is uncontrolled it gives rise to higher plants and trees. The acidic secretion produced by lichens induces a bio-corrosion in stones. The surface is rendered damp and soft. Causes unsightly appearance and results in progressive damage. Laterite, unlike other stones, is weak and porous and serves as a good background for vegetation. Trees grow fast on laterite. Rough surface texture and clay filled cavities allow easy propagation of roots. If plant growth is uncontrolled, it causes progressive damage leading to collapse of the building as seen in the ruins of St. Augustines tower, Old Goa.


(a) Growth of moss and lichens (b) Damage due to growth of trees

Figure 5 : Bio-degradation.

### *3.3 Salt crystallization*

Formation of efflorescence on exposed surfaces of structure causing unsightly appearance. Formations of salt crystals below the exposed surface result in blistering and scaling of outer layers. Salts seeps into the building by capillary action of ground water. Salts are deposited within the structure (in basement portions) near the exposed surfaces resulting in granular disintegration (as illustrated in Fig. 6b).

(a) Efflorescence due to deposition of salts on surface (b) Progressive damage due to deposition of salts internally

Figure 6 : Salt crystallization attacks on Laterite.

### *3.4 Human Interventions*

Improper repair to laterite structure can damage the structure like repair of soft laterite using a hard cement mortar. Cement mortar creates a hard rigid boundary around the material. The expansion and shrinkage of the material due to thermal variation cycles within the hard rigid boundary leads to formation of cracks and disintegration of material. Neglect and vandalism are other forms of damage induced by human intervention.

## 4 DISCUSSION

Weathering damages, namely, loss of material, bio-degradation and salt attack occur due to presence of dampness. Source of dampness in the exposed wall areas may be due to driving rain or capillary rise of ground water. However, it was noticed that the decay was not due to a single cause, but a combined action of various causes. Salt attack occurred due to ingress of salts into the structure (from atmosphere and ground) by moisture migration. The salt decay found in the basement portions of buildings suggests that the salts must have originated mainly from ground by capillary action.

The maximum damage seen in exposed laterite structures was due to bio-degradation such as growth of moss and lichens and vegetation. The warm humid climate and inherent properties of laterite (high water absorption) provide a conducive environment for growth of vegetation. Growth of moss and lichens cause unsightly appearance and material destruction. Formation of moss and lichens on exposed laterite renders the surface damp and soft, which promotes growth of higher plants and trees. Protecting the walls from dampness will control salt attack and bio-degradation.

## 5 EXPERIMENTAL STUDIES: ENGINEERING PROPERTIES

Fresh laterite blocks of standard size (38 × 19 × 19 cm) were obtained from 4 representative quarries identified for large volume of laterite mining in Malabar region of Kerala. Cubical specimens of 15 cm side were cut using rotary saw machine to determine the compressive strength as per ASTM standards (ASTM C170 2004). Specimens were tested both in oven dry and saturated condition. Specimens were oven dried for 48 hours at 60 ºC to constant weight and allowed to cool to room temperature. For testing in wet condition specimens were immersed in water for 48 hours to constant weight. Specimens were capped using plaster of Paris to ensure the loading faces of the specimens parallel to the platens of platens of testing machine by applying an initial load. A minimum of five specimens were tested for each condition and average compressive strength was determined. The range of maximum and minimum values obtained from the test is reported in Table 1. Properties such as specific gravity, water absorption, porosity and strength were determined as per ASTM standards (ASTM C 97 2003) and the results are also presented.

Experimental study of laterite from representative quarries of Kerala reveals a wide variation in engineering properties implies the need for testing before its selection for repair measures. Substantial reduction in strength due to saturation suggests the need for protection of laterite structures from dampness.

Table 1 Physico-mechanical properties of Malabar Laterite

| | | |
|---|---|---|
| Compressive strength ( MPa) | Saturated | 1.3- 4.5 |
| | Oven dry | 4.4- 8.3 |
| Water absorption (%) | | 10.5- 17.9 |
| Specific gravity | Saturated surface dry | 2.36- 3.04 |
| | True specific gravity | 2.84-3.58 |

## 6 SUMMARY

It is evident that with appropriate selection, laterite structures remain in good serviceable condition for many years with less maintenance as seen in prehistoric megalithic structures of Kerala. Weathering damages namely granular disintegration, bio-degradation and salt attack are the main cause of weathering which occur mainly due to the presence of moisture. Dampness was identified as a major factor which induces deterioration and hence protection from dampness would prolong the life of laterite monuments. It is also found that the decay process is due to a combined mechanism of several causes.

It is seen that the compressive strength of laterite from Malabar region shows wide variation (1.3 - 4.5 MPa). The strength properties are comparable with that of ordinary bricks (3.5 MPa). High moisture absorption of the material (up to 17 %) suggests that the material can hold and conduct large amount of water, which promotes the growth of vegetation and microorganisms. The reduction in strength due to saturation suggests that adopting suitable damp protection for laterite walls. The hygric properties like permeability and porosity of laterite have to be studied to suggest suitable damp-proofing methods. This study forms a base for maintenance activities and to suggest appropriate restoration strategies.

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