Decay Diagnosis of Goan Laterite Stone Monuments

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ABSTRACT

Heritage monuments in laterite stones have suffered from harmful intervention during restoration due to inadequate research done on laterite as masonry material based on its great regional variation and mixed property of stone, brick and soil. To preserve these structures, it is crucial to conduct monument investigation for defect analysis along with characterization of local laterite. This research was undertaken for decay diagnosis of Goan laterite monuments with the Basilica of Bom Jesus, India as a case study along with a combination of field and laboratory tests on freshly quarried stones.

During the monument investigation, a majority of the 20 visible defects indicated that efflorescence and biological growth due to water ingress were responsible for deterioration. An in-situ profile study of the quarry showed that though the stone was a matured variety of laterite, however presence of salt, clay-mineral, quartz, and iron patches were responsible for efflorescence, high water absorption, hard patch, and staining respectively. Hence a megascopic study was required for obtaining good quality masonry material. From laboratory tests on freshly quarried samples for geochemical-mineralogical, physical and engineering properties, again it was proved that durability of laterite masonry was attributed to water tightness rather than strength. Physical protection from water by design detailing or application of preservative treatment for water proofing can significantly enhance the lifespan of monuments.

KEYWORDS

Decay diagnosis, Laterite masonry, Monument investigation, Preservative treatment, Water ingress

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1 INTRODUCTION

Laterite is a weathered rock found in tropics and sub-tropics and is named after the Latin word 'Later' or brick [Buchanan, 1807]. Numerous monuments including prehistoric megaliths of Kerala and world heritage sites of churches of Goa, India, third generation Angkor temples or walls in Group G monuments of My Son, Vietnam are made of laterite. Laterite is neither soil nor does it belong to the triplet group of including igneous, metamorphic and sedimentary rocks [Aleva, 1994]. On the contrary, due to its mixed property of stone, brick and soil, laterite has remained as a subject of controversy among geologists and engineers over a century [Banerjee, 1998]. Perhaps this is the only stone that is soft during quarrying, hardens after atmospheric exposure [Gidigasu, 1976; Nichol, 2006], and yet requires a waterproofing plaster and a dense damp proof course [Das, 2007].

Great regional variations has hindered in depth research to characterize laterite as masonry material. It has lead to harmful interventions during restoration of monuments [Bhandari, 1995; Engelhardt, 2005]. To preserve these heritage structures, it is of paramount importance to conduct a comprehensive decay diagnosis comprising of: (1) monument investigation for identification of defects and their analysis; and (2) characterization the local laterite as masonry material. To address this knowledge gap, the current study was undertaken to investigate Goan laterite block masonry with the Basilica of Bom Jesus as a case study. Old Goa on the west coast of India is known as 'The Vatican of East' for its group of beautiful Baroque churches. This 16th century basilica built by the Portuguese rulers is a world heritage monument and is one of the best examples of fine ashlars masonry in Goan laterite [Rajagopalan, 1987].

2 RESEARCH METHODOLOGY

For any natural stone, its composition and microstructure determine its engineering properties and durability [Fitzner, 2000]. The properties of laterite vary widely with location and depth of the quarry [Kasthurba, Santhanam & Mathews, 2007]. Moreover its hardness depends on: (1) degree of weathering of parent rock [Gidigasu, 1976]; (2) quantity, nature and distribution of iron [Alexander & Cady, 1962] and (3) homogeneity, structure and age [Maignien, 1966]. Hence for a thorough understanding of the decay mechanism of laterite, a three pronged approach had been adopted in this study:

- Monument investigation to identify the signs and causes of decay.
- Profile study at a local quarry to study depth-wise variation of laterite of that region.
- Laboratory experiments on freshly quarried stones to determine its engineering properties.

2.1 Monument Investigation

A detailed field study at the basilica was conducted just after the rainy season for easy identification of defects. Only non-destructive tests were allowed at this protected site, hence the investigation was limited to expert walkthrough, photo documentation of the defects, discussion with the personnels of Archaeological Survey of India (ASI) and review of past restoration records.

2.2 Field Survey

The in-situ testing was carried out at Patradevi quarry at north Goa for a profile study and qualitative strength tests. Patradevi was selected for this research due to the fact that stones from this active quarry have similar characteristics as that of the original stones used in the monument and is highly recommended by ASI, for restoration of Goan monuments [Architectural Conservation Cell, 1999]. A detailed profile study of the exposed vertical face of matured laterite layer was conducted. A depth-wise variation of surface hardness as a qualitative indicator of strength was measured for a particular profile using Type P pendulum hammer [Proceq, 2003]. About three tons of samples were collected from various depths, marked, sealed in wooden crates and transported to the laboratory.

2.3 Laboratory Experiments

As mentioned earlier the engineering property and durability of laterite is a function of its chemical composition and microstructure, hence the following test programme was developed to study the engineering properties of laterite:

- Chemical or wet analysis: gravimetric method for impure silica and volumetric method for Fe_2O_3, Al_2O_3 [IS 2720: Part 25]
- Atomic absorption spectrometry for trace alkali metals [Varma, 1985]
- Petrography thin section study for maffic [dark] and felsic [light] mineral [DIN EN 12407]
- X-Ray diffraction [XRD] analysis for altered clay minerals [Moore & Reynolds, 1997]
- Test for water absorption, specific gravity and porosity [DIN 52103]
- Test for water absorption coefficient through capillary action [DIN EN 1925]
- Test for compressive strength [DIN 52105] and flexural strength [DIN 52112]
- Salt crystallization test [DIN 52111]

3 RESULTS AND SISCUSSION

3.1 Findings from Monument Investigation

From the internal reports of ASI [1964-1999], it was noted that majority of the problems started in 1930s after de-plastering of 2m thick walls to solve the problem of water seepage through them. As it was difficult to introduce a damp proof course, external lime plaster was peeled off to apply paper poultice for removal of efflorescence. Since that date various restoration activities have taken place. Most of these interventions were irreversible in nature and had shown detrimental effect in the long run. For example, walls lost breathability due to the application of acrylic paint on inner surface, stronger cement mortar used for re-pointing was incompatible with soft stone, pruning effect of pulling and plucking to prevent vegetation growth in reality resulted in abundance of vegetation etc.

Most of the decay features were found to be associated with the external walls only, except very few surface cracks in floor and ceiling. Twenty visible defects were identified and grouped into 5 major categories [Weathering Research Gr., 2003], namely: (1) mechanical weathering; (2) efflorescence; (3) material and methods of construction; (4) human intervention and (5) biological decay (Table 1).

3.2 Findings from Field Study

Patradevi is an active quarry. Hence, the strata such as duricrust, lithomerge and parent rock were not observed. The visible laterite zone was about 9m deep appeared as a uniform brick wall without any significant variation. However, a close inspection revealed patches of salt, clay, quartz and iron which may lead to efflorescence, water absorption, hardness and staining respectively (Figure 1).

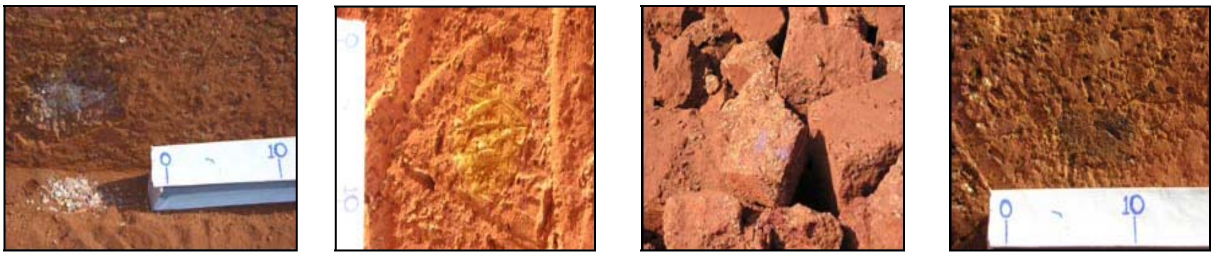

Figure 1. Defects found by visual inspections (L to R: patches of salt, clay, quartz and iron)

Table 1. Summary of decay features.

Category	*Description of defects*	*Probable cause*
Mechanical weathering	Granular disintegration	Cement holding the grains together is weakened by water and washed away.
	Flaking (depth <5mm)	Salt weathering and wetting-drying cycle
	Scaling (depth >5mm)	Accumulation of salt at a frequent wetting depth within the stone and the eventual lifting away of the outer layer
	Honeycombing	Merging of adjacent depressions due to multiple flaking, granular disintegration and salt accumulation
	Caverns	Severe honeycombing
Efflorescence	Salt patch / stain	Lashing rain and rising moisture
Materials and methods of construction	Inadequate plinth protection	The conventional practice of a nonporous granite damp proof course is absent
	Loss of mortar	Poor workmanship at pointing leaves the mortar joints weak and susceptible to rainwater ingress.
	Cracks by corrosion	Volume increase of iron fixing due to corrosion
	Heterogeneity	Inferior quality blocks placed along with good ones become weak point for a wall
	Widening of joints	Due to absence of drip course, the water follows the mouldings and gets absorbed through mortar joints.
Human intervention	Incompatible mortar	Stronger cement mortar used for re-pointing of soft stone
	Peg mark	Use of pegs to maintain uniform plaster thickness
	De-plastering	Repair work
Biological decay	Biological colonization & fern growth	High silica content and presence of moisture
	Bio-chemical weathering	Formation of dark crust due to leaching of iron at the places of root penetration
	Cracks	Root penetration through soft and porous stone
	Deformation	Thick roots causing dislodgement of stone blocks

3.3 Findings from Laboratory Experiments

3.3.1 Geochemical and Mineralogical Analysis

Laterite samples from upper, middle and bottom level of quarry was tested for major oxides and trace elements (Table 2). As the depth-wise variation in both field investigation and chemical composition was found insignificant, in later studies depth of quarrying was no more considered as a criteria. High silica content implied a high amount of clay responsible for water absorption.

Table 2. Quantity of major oxides and trace elements

Sample No	*Major oxides [%]*				*Trace elements [ppm.]*			*Total*
	SiO_2	Fe_2O_3	Al_2O_3	*LOI*	Na^+	Ca^{++}	Pb^{++}	[%]
GA1 (upper)	52.34	21.79	9.22	14.23	150.09	8.34	332.60	97.58
GA2 (middle)	57.73	16.34	8.93	16.23	162.83	15.23	310.50	99.23
GA3 (bottom)	54.54	18.86	10.45	15.05	170.47	22.69	277.50	98.90
Average	54.87	19.00	9.53	15.17	161.13	15.42	306.87	98.57

XRD analysis detected abundance of clay minerals namely, kaolinite, biotite and chlorite (Figure 2). According to Schelmann's [1981] definition the high content of secondary silica indicated matured variety of laterite. Petrographic analysis of thin sections (Figure 3) revealed presence of both: (1) maffic mineral (haematite and red iron oxide) and (2) felsic minerals (feldspar and quartz).

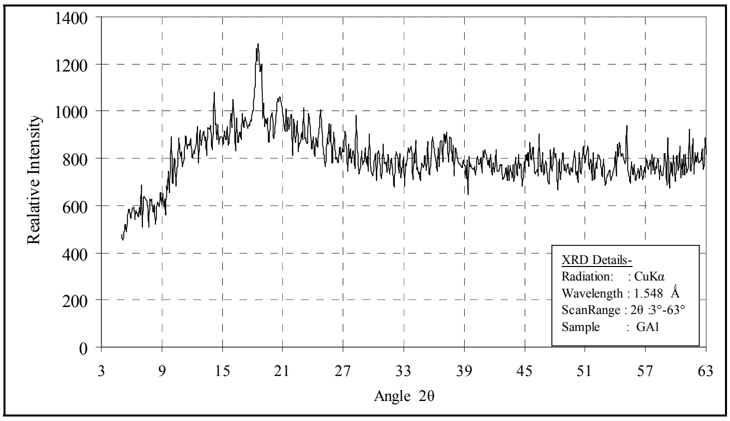

Figure 2. Result of X-Ray difractogram

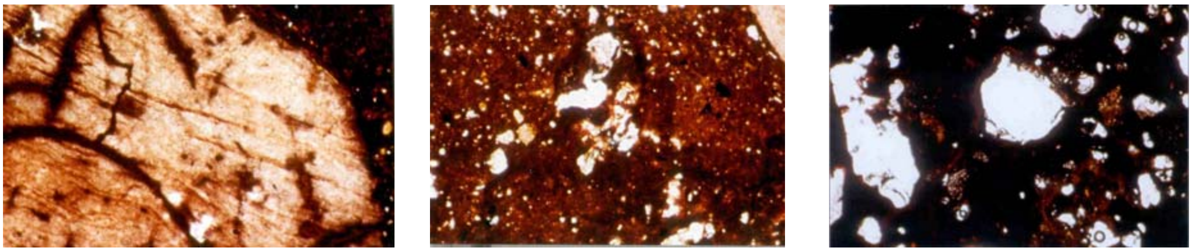

Figure 3. Result of thin section study

3.3.2 Physico-mechanical Analysis

Results of the physico-mechanical analysis is presented in Table 3.In spite of the difference between apparent and true specific gravities, the apparent and true porosities had similar values. Although the high porosity of laterite was reaffirmed in this result, it is difficult to explain the difference in the specific gravities or in other words, it is not easy to suggest that all pores in the system were interconnected. This anomaly might be a result of the fact that while measuring the actual saturated surface dry (SSD) mass of the specimen, it is almost impossible to keep the near-surface pores fully saturated. Average value of water absorption was found as 11.45%. Both porosity and water absorption were fairly low while compared to range of standard values [IS 2720: Part 25] indicating a matured variety of laterite. The value of 1641 g/m² / min$^{0.5}$ for coefficient of absorption through capillarity was found to be lesser than that of sandstones [Jäger & Burkert, 2002]. Hence it can be concluded that though laterite is porous, numbers of micro-pores are less and not susceptible to capillary action.

Table 3. Results of physico-mechanical tests

Properties	*Sub-properties*	*Values*	*Unit*
Capillarity	---	1641	g/m² / min$^{0.5}$
Water absorption	---	11.45	%
Specific gravity	Bulk	1.79	---
	SSD	1.99	---
	Apparent	2.25	---
	True	3.06	---
Porosity	Apparent	25.75	%
	True	26.48	%
Compressive Strength	---	5.05	MPa
Flexural strength	---	1.23	MPa

The average values of compressive and flexural strength of the sample were found to be 5.06 MPa, and 1.28 MPa respectively (Table 3). This indicates that laterite is a weak stone, even weaker than good quality brick [IS 1077]. This value is much lower than the calculated average strength of 10.3MPa found from rebound hammer test. Such a large difference in values occurred because in quarry a continuous surface was tested while the manufacturer's conversion graph was meant for 20 cm cubes.

3.3.3 Salt Crystallization Test

In the salt crystallization test of 15 weathering cycles, there was sharp weight gain of 5.07% on the first day but the rate of weight gain became steady up to 8-th cycle with a marginal difference within 3%. The large surface-pores accumulated salt crystals to a great extent on the very first day. As more salt solution seeped in, there was a slow but steady weight gain. Between 6th and 8th weathering cycles, specimens showed rapid weight loss of 4.7%. But during next three cycles, though there was again weight gain, but in later cycles the specimens started losing integrity and finally almost crumbled down (Figure 4). Probably during 6th to 8th cycles, resistance of samples was lost by a considerable extent such that pressure exerted by volume increase of salt crystals dislodged a few grains. Assuming most of these grains were internal, it can be concluded that some previously inaccessible pores might have got exposed to salt solution allowing more salt to enter, crystallize and cause weight gain. But in later stages, the excessive amount of salt had a splitting effect on week laterite and hence caused total disintegration of the specimens.

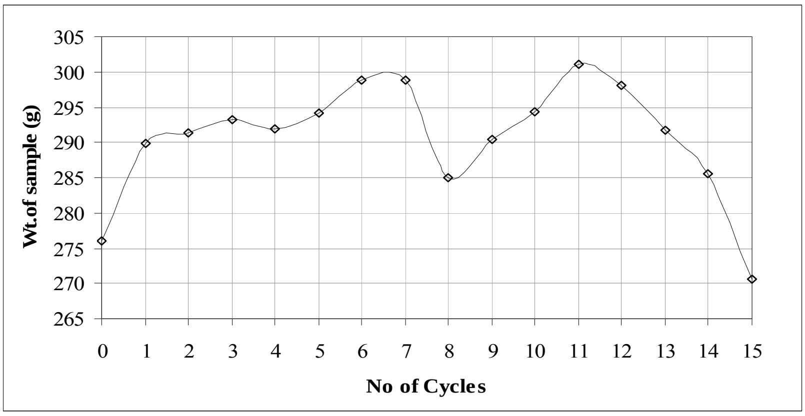

Figure 4. Result of salt crystallisation test

3.4 Discussion

From the monument investigation, the root cause of most of the defects was identified as water ingress either from lashing rain or from rising moisture leading to salt efflorescence and vegetation growth. Until1930, application of lime plaster before each monsoon prevented the harmful weathering actions to a great extent. Structural failure was not visible, hence a preliminary conclusion can be drawn that durability of laterite is more dependent on water tightness rather than strength. At local quarry, no significant depth-wise variation was found, but presence of clay minerals affirmed that though Goan laterite is a matured and stronger variety of laterite, it is susceptible to water ingress. Laboratory testing affirmed these facts. It was also found that though the stone has high porosity, the pores might not be interconnected and large enough to resist capillary action.

4. CONCLUSION

Goan laterite was tested at a world heritage monument, at local quarry and in laboratory using chemical analysis, petrographic microscopy, and physical tests to determine the decay mechanism. Most of the defects were as a result of water ingress. At quarry a matured type of laterite with less variance with depth was observed. Hence through megascopic analysis, good quality masonry material can be selected to achieve the first line of defence against weathering. In spite of high content of strength-giving iron oxide, Goan laterite is weak in compression and flexure even compared to standard brick. Hence the durability of masonry was attributed to water tightness rather than strength. It can also be concluded that water repellence in the form of design detailing or water proofing agent can significantly improve the life span of monuments built in Goan laterite. The facts obtained from this study can contribute to an integrated database of laterite research and can be applied in the development of stone preservatives enhancing the pore structure and water tightness.

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REFERENCES

Aleva, G.J.J. (Compiler). 1994, *Laterite–Concepts, Geology, Morphology & Chemistry*, ISRIC, Wageningen, Netherlands.

Alexander, L.T. & Cady, J.G. 1962, 'Genesis and hardening of laterite in soils', *U.S. Dept. of Agriculture Technical Bulletin*, **1281**, 1-10.

Architectural Conservation Cell, 1999, *Methodology and Actual works of Restoration of The Chapel of Our Lady of Mount, Old Goa*, Associated Cement Company Ltd. Thane.

Archaeological Survey of India (ASI). 1964-1999*, Internal Reports*. Author, New Delhi, India.

Banerjee, P.K. 1998, 'Basic research on laterites in tropical countries', *Quaternary Int.*, **51/52**, 69-72.

Bhandari, C.M. 1995, *Saving Angkor*, White Orchid Press, Bangkok.

Buchanan, F. 1807, *A Journey from Madras Through the Countries of Mysore, Canara and Malabar*, T. Cadell & W. Davies, London, (Reprint, 1988, Asia Educational Services, New Delhi).

Das, S. 2007, 'Laterite monuments of India', *Const. History Society Newsletter,* UK, 15-19, May.

DIN 52103. 1988, *Testing of Natural Stone and Mineral Aggregates - Determination of Water Absorption and Saturation Coefficient*, Deutsches Institut für Normungm (DIN), Berlin.

DIN 52105. 1988, *Testing of Natural Stone – Determination of Compressive Strength*, DIN, Berlin.

DIN 52111. 1990, *Testing of Natural Stone and Mineral Aggregates - Crystallization Test with Sodium Sulphate*, DIN, Berlin.

DIN 52112. 1988, *Testing of Natural Stone – Determination of Flexural Strength*, DIN, Berlin.

DIN EN 1925. 1999, *Natural Stone Test Methods - Determination of Water Absorption Coefficient Capillarity*, DIN, Berlin.

DIN EN 12407. *Natural Stone Test Methods - Petrographic Examination*, DIN, Berlin.

Engelhardt, R. 2005, *Safeguarding My Son World Heritage – Demonstration and Training in the Application of International World Heritage Standards of Conservation at My Son Group G Monuments*, UNESCO Project Terminal Report, UNESCO, Bangkok

Fitzner, B. 2000, 'Damage index for stone monuments: protection and conservation of the cultural heritage of Mediterranean cities', Proc. of the 5th International Symposium on Conservation of Monuments in the Mediterranean Basin, Sevilla, Spain, pp. 677-689.

Gidigasu, M. D. 1976, *Laterite Soil Engineering – Autogenesis and Engineering Principles*. Elsevier Scientific Publishing Company, Amsterdam.

IS 1077. 1992, Common *Burnt Clay Bldg. Bricks – Specification*, Bur. Indian Standards, New Delhi.

IS 2720: Part 25. 1982, *Standard Method of Test for Soils: Determination of Silica Sesquioxide Ratio*. Bureau of Indian Standards, New Delhi, India.

Jäger, W. & Burkert, T. 2002, *Verwendung Modifizierter Siliciumdioxid-Nanosole zum Schutz und zur Konsolidierung von Umweltgeschädigten Kulturgütern aus Sächsischem Elbsandstein am Beispiel der Skulpturen der Fasanerie Moritzburg*, TISA Research report, TU-Dresden, Germany.

Kasthurba, A.K., Santhanam, M., & Mathews, M.S. 2007, 'Investigation of laterite stones for building purpose from Malabar region, Kerala state, SW India – part 1: field studies and profile characterisation', *Construction and Building Materials,* **21**[1], 73–82.

Maignien, R. 1966, 'Review of research on laterites', *Natural Resources Research IV*, UNESCO, Paris

Moore, D.M. & Reynolds, R.C. 1997, *X-Ray Diffraction and the Identification and Analysis of Clay Minerals (2 Ed)*, Oxford University Press, USA.

Nichol, D. 2006, 'The geo-engineering significance of laterite construction in Goa, SW India', *Quarterly Journal of Engineering Geology and Hydrogeology*, **33**[3], 181 – 185.

Proceq. 2003, '*Portable concrete testing instruments for non-destructive. site investigations'*, http://www.procequsa.com/documents/Proceq_Concrete_Line_Catalog_72.pdf (retrieved Oct 19, '03).

Rajagopalan, S. 1987, *Old Goa*, Archaeological Survey of India, New Delhi.

Schellmann W. 1981, 'Considerations on the definition and classification of laterites', Proc. the Int. Seminar on Laterisation Process, Trivandrum, India, pp. 1–10.

Varma, A. 1985, *Handbook of Atomic Absorption Analysis Vol. 1*, CRC Press, Boca Raton.

Weathering Research Group 2003, '*Weathering features tutorial'*, http://www.qub.ac.uk/geomaterials/weathering/weatheringfeatures.html (retrieved Sept., 22, 2003).