Characterization of Tenth Century Ancient Building Materials of Seenakesavaperumal Temple, Yelagiri village, Tamil nadu

Shivakumar M, Thirumalini Selvaraj

Abstract: A characterization study on performed on the extracted stone masonry, Cement and lime mortar samples from the seenakesava Perumal temples, Yelagiri been constructed during chola period (1100-1150 AD). The samples were extracted out to understand the raw materials and the ancient application technology. The binder is hydraulic lime with binder to aggregate ratio of 1:2.5-3. The extracted stone samples and brick bedding mortar revealed high range of quartz and feldspar with minor peaks of calcite through X-ray diffraction (XRD) technique. Rather than calcite the (CSH & CAH) formation reflects the load bearing phases and may be the reason behind the longevity of the thousand-year-old temple. XRD expressed the high range quartz and feldspar with minor fractions of MgO and similarly the locally procured local quarry samples revealed the same intensity peaks. This study has simulated the ancient construction materials with modern materials to replicate the similarly performed construction materials to preserve from the environmental conditions and the cultural heritage of the country.

Keywords: stones, brick & bedding mortar, lime mortar, & material characterization (XRD).

I. INTRODUCTION

Indian assorted cultural heritage is rich with different forms of ancient built structures and architectural monuments with artistic craftsmen capabilities. Most commonly the structures that is of archaeological or historical artistic interest and that still existing for more than centuries said to be ancient monuments. From the recent studies the holistic approach in preparing the repair mortar to regain the original mortar or building materials is bringing back the traditional methodology to strengthen the ancient structures and monuments (Shore, 2018). Hence the reverse methodology technique is essential in this century, since after the downfall of lime mortar constructions due to invention of Portland cement in 19th century, that basically improved the rate of construction but failed to overcome the longevity, durability and external environmental conditions. Ancient structures interacted with natural organic herbs and locally available additives into mortar to increase the strength and durability of the structures. Researchers also has also suggested that addition of natural organics has improved the carbonation stages as the curing time increased (Jayasingh 2019). Identification of a right material and appropriate technique could ensure better performance of the lime mortar with age. In this study, characterization of ancient building materials of seenakesava perumal temple was carried out in order to investigate on the bulged stone masonry wall and to study on the computability of materials used during construction to simulate the repair mortars and restore the masonry walls with modern analytical techniques (Diekamp 2013). Seenakesavaperumal temple is nearly 1000 years old and one of the ancient perumal temples in Tamil nadu, India. It was constructed at (1100-1150 AD) during the chola’s and pallava periods. The temple is located close to yelagiri hills of Tamil nadu in southern India surrounded by Jawadhu and yelagiri hills. It lies between 12°52′30″ N latitude to 78°15′ 00″ E longitude. The condition of the temple is in a very bad state and almost the structure has sunk 5” feet under the earth from the original surface and which has dislocated the masonry wall due to severe environmental conditions. The characterization study of materials used and the technology adopted for construction of the temple is necessary to carry out the restoration work. Hence, this characterization study will be highly useful for restoration of chola’s period temples in and around Tamil nadu. As the temple lies just few meters away from the yelagiri hills, thus indicates the usage of stones to construct the temple from the large crushed boulders from the hills Fig 1.

Fig 1. Location of seenakesavaperumal temple (a) Tamilnadu district map (b) The google earth location of the temple.

II. MATERIALS & METHODS

From Fig 2 seenakesava perumal temple, the samples were extracted from interior and exterior locations and were also grouped as (SKP-1.SKP-2 -SKP-3, SK-4) respectively. The descriptions of samples were presented and sampling locations were shown in respectively Table 1. Extracted samples were collected from the upper heights of the structure to avoid the capillary rise (Ravi 2016). Temple raw materials namely stone, bedding mortar, brick, lime mortar, and cement mortar samples were collected to find the match with the
conventional building materials to restore the structure. Intense care was taken on the undisturbed spots during to avoid the adjacent cracking.

### Table 1. Sampling location of historic building materials

| Sampling points | Description |
|-----------------|-------------|
| SKP-1           | Exterior of the wall (1-5) stones samples Fig (a, b) |
| SKP-2           | Brick & bedding mortar at ceiling slab Interior-2 |
| SKP-3           | Interior of the wall samples at sanctum of Garbhagriham-3. |
| SKP-4           | Cement mortar samples from interior temple joints-4. |

Fig 2. Wall samples of temple (2), Brick mortar sample (3), Temple garbhagriham sample (4). Cement mortar sample.

**Fig 3.** Specimens extracted locations (a, b, c, d).

**Fig 4.** Plan & sampling locations of seenakesavaperumal temples, Yelagiri, Tamilnadu.

### III. ANALYTICAL TECHNIQUE

#### A. X-Ray Diffraction (XRD)

Each extracted sample were gently crushed and sieved through 75µm and processed through X-Ray Diffraction (XRD) analysis using Desktop Diffractometer working with the Cu K-alpha radiation (k = 1.54182), and graphite monochromator in the diffracted beam, at 1.5 kW and interpretation by Bruker DIFFRAC.SUITEEVA software. It gives qualitative result on the possible presence of minerals in the mortar samples (Middendorf 2005). The cumulative graphs from the respective samples were investigated through Expert high score software using joint committee on powder diffraction standards JCPDS data library.

### IV. RESULTS & DISCUSSIONS

The mineralogical characterization indicates that the historic samples is amorphous polycrystalline in nature since it has a greater number of peaks due to the mixture of crystal orientations.
Fig 5. (a). SKM-1 XRD results of exterior extracted samples (b) XRD of Local quarry samples.

The XRD results of SKM-1 from the Fig 5 reveals the major quartz peaks with JCPDS diffraction file (085-0797) with d-spacing angle of 3.34Å at 12.34º, 26.64º & 26.95º respectively was investigated with the Expert high score software with 2θ Positions library. Further the minor range peaks of feldspar ranged at 31.65º and 35.63º indicates the reason behind the product hardness, durability and resistance to chemical corrosions Alejandra (2015). Magnesia peaks (078-0430) and olivine peaks (075-1156) were also visible at 47.04º and 68.15º acts as refractory material to act as thermal resistance in the building units Westgate (2019).

Fig 6. (2). Brick mortar sample XRD results (3). Inner sanctum (Garbhagriha) stone sample XRD.

The XRD graph Fig 6. The brick mortar sample mainly contained high range of quartz peak positioned at 24.26º, 26.64º, 46.54º, 52.13º, 68.85º and 82.34º with JCPDS diffraction phase identity (33-1161). The XRD peaks also simultaneously reveals the calcite peaks due to bedding mortar interaction with bricks. The calcite peaks which indicates the carbonated stage of the mortar positioned at 38.93º, 48.93º & 49.92º with JCPDS file number (003-0670). Supportive complex compounds like feldspar, magnesia and aluminium oxide peaks were also visible with high ranges indicating the long-time durability and load bearing phases in the binder materials Ravi (2018). Fig 6(3) XRD graphs shows the internal stone sample of sanctum prone to heat, changing the stone to pitch black as shown in Fig 2. Quartz peaks are scattered at 11.31º, 14.56º, 26.64º and the low range of olivine peaks which is a magnesium iron silicate form acts as high pressure polymorphs of siliceous compounds. Feldspar and magnesia peaks are at higher ranges indicates the thermal resisting conditions at the inner sanctum, reveals that lot of heat is been absorbed for centuries and might be reason behind weathering of stones Gour (2018). The stone samples have to be completely restored to avoid the dislocation of the stone masonry wall.
The XRD graphs Fig 7 shows the high range of Quartz peaks (33-1161) positioned at 26.64°, 50.14° and 59.94° respectively. The binder to aggregate ratio for cement mortar may be proportioned at 1:3 during the ancient production technology. It also reveals that complete transformation of calcite from complex compounds of CSH & CAH. Metastable compounds namely vaterite and aragonite at higher ranges are observed indicates the shell lime may be added during the production technology to enhance the mechanical properties Ventola (2011). The presence of portlandite peaks inside the temple sanctum was observed in graph indicates the presence of hygroscopic properties due to inner sanctum are not directly exposed to atmosphere air and humid environment Shore (2018). Hence the carbonation has delayed in the cement mortar in the inner sanctum sample of the temple. Hence in this present XRD semi quantification study on binder/aggregate proportions have been detailed.

V. COLLECTIVE INFORMATION

Historic samples were also collected from the nearest location to the temple, to investigate on the compatibility of modern conventional stone and building materials to simulate back the original mortar to the temple (Fig 8, Fig 9). The local informative study was conducted regarding the collection of samples and ancient production methodology techniques that could have prevailed for many centuries. As the reason the collection of samples were made from yelagiri hills and stone samples closer to the temple with lime stone mining quarries at the nearest location namely Vellore, cuddalore and Tiruvannamalai etc. The different types of limes were procured to simulate the properties and analytical XRD analysis was performed and cumulative results were examined for further knowledge.

A. XRD interpretation on Locally collected stones

Fig. 7. Cement mortar sample from the inner roof ceiling of the temple.

Fig. 8. Simulation stone sample from nearest location of the temple.

B. XRD interpretation on Limes

Fig. 9. XRD on limes (a) Dry slaked lime (b) Hydraulic lime.

VI. CONCLUSIONS

The characterization study is competent with sufficient analytical technique employed with compatibility of building materials. The altered and unaltered samples were
extracted from four location with intense scientific knowledge on materials. The results of each test were validated through XRD expert high score data library to further introspection on the presence of elements with JCPDS diffraction file. XRD results indicated the high range of Quartz formation with supportive compounds that have enhanced the strength of the stone masonry wall from complete dislocation and environmental conditions. The compatibility study was shown with similar peaks to match up the stone sample from the nearest location to restore the complete masonry wall. Teutnico (2006) stated that compatibility as the “new materials should be as durable as possible without (directly or indirectly) causing damage to the original material”. The XRD interpretation clearly indicates the hydraulic lime mortar may be incorporated during lime mortar production in the ratio of 1:3 for bedding mortar in agreement with XRD peaks intensity. Similarly, the recent restoration has cement mortar at few locations which indicated the portlandite peaks in the XRD graphs. Newly restored mortar were not exposed to open atmosphere and with humid environments, which clearly indicates the low pozzolanic action and decrease in carbonation properties. All the temple building material samples that were collected from the nearest location revealed the positive approach towards similar results of peaks against the XRD interpretation. Hence this study can be adopted scientifically to restore the 1000 years old chola’s structure and also the further studies can be progressed with higher end analytical techniques as XRF, SEM-EDX, TGA-DTA and microscopy study on the ancient materials.

FUTURE SCOPE

From the overall study, the historical samples have revealed the material properties with preliminary analytical testing methods, further the modern sophisticated analytical methods like FT-IR, TGA-DTA, SEM-EDX, Petrographic studies will enhance the production methods and microstructural evaluation of the traditional mortars.

ACKNOWLEDGEMENT

The authors wish to express their sincere thanks to Hindu religious and charitable endowments, Tamilnadu for permitting to extract the historic samples.

REFERENCES

1. Alejandra, J(2015) ‘Ge-conservación Influence of inorganic and organic additives on spectrophotometry of lime mortars’.
2. Diekamp, A.(2013) ‘Lime mortar with natural hydraulic components: Characterisation of reaction rims with FTIR imaging in ATR-mode’, RILEM Bookseries, 7(September), pp. 105–113. doi: 10.1007/978-94-007-4635-0_8.
3. Gour, K. A., Ramadas. (2018) ‘Revamping the traditional air lime mortar using the natural polymer – Areca nut for restoration application’, Construction and Building Materials. Elsevier Ltd, 164, pp. 255–264. doi: 10.1016/j.conbuildmat.2017.12.056.
4. Jayasingh, S. and Selvaraj, T. (2019) Structural Analysis of Historical Constructions. Springer International Publishing. doi: 10.1007/978-3-319-99441-3.
5. Middendorf, B. (2005) ‘Investigative methods for the characterisation of historic mortars - Part 1: Mineralogical characterisation’, Materials and Structures/Materiaux et Constructions, 38(28), pp. 761–769. doi: 10.1617/14281.
6. Ravi, R., Selvaraj, T. (2016) ‘Characterization of Hydraulic Lime Mortar Containing Opuntia focus-indica as a Bio-Admixture for Restoration Applications’, International of Architectural Heritage, 10(6), pp. 714–725. doi: 10.1080/15585308.2015.1109735.
7. Ravi, R., Thirumalini, S. (2018) ‘Analysis of ancient lime plasters – Reason behind longevity of the Monument Charminar, India a study’, Journal of Building Engineering. Elsevier Ltd, 20(July 2017), pp. 30–41. doi: 10.1016/j.jobe.2018.04.010.
8. Thirumalini, S et.al (2018) ‘Analysis and Characterisation of Third Century Ancient Mortars At Subramanyaswamy Temple Rediscovered After the 2004 Tsunami Near’, seashore (1), pp. 25–38.
9. L. Ventola et.al (2011) ‘Traditional organic additives improve lime mortars: New old materials for restoration and building natural stone fabrics’, Construction and Building Materials, 25(8), pp. 3313–3318. doi: 10.1016/j.conbuildmat.2011.03.020.
10. West, P, Ball, R. J (2019) ‘Olive as a reactive aggregate in lime mortars’, Construction and Building Materials, Elsevier Ltd, 195, pp. 115–126. doi: 10.1016/j.conbuildmat.2018.11.062.

AUTHORS PROFILE

Dr.S. Thirumalini, Associate professor at Department of structural & Geotechnical engineering, Vellore Institute of Technology, Vellore, Tamilnadu, Her primary areas of research include developing of scientific methods of restoration of heritage structures, chemistry of original construction materials used in Indian heritage structures and development of carbon capture technology in buildings using organics additives and lime to promote their sustainability. Role of organic additives was studied and nature and carbonation potential of organic lime mortars were investigated in detail. She has investigated on the carbonation process of lime admixture with natural organics such as Terminalia chebula, Jaggery (unrefined sugar) and plant extracts from Cactus, Cissus Glaucus Roxb and their behaviour. Moreover, working on new old materials in civil engineering, bringing out the sound scientific proof for the use of ancient eco-friendly admixtures in construction.

Shivakumar M, pursuing his Ph.D. from Vellore institute of Technology, Department of Structural and Geotechnical Engineering, Vellore, Tamilnadu. He has completed MTech (Construction technology) from Visvesvaraya Institute of Technology, Bangalore in 2015 and B. E (Civil Engineering) from Visvesvaraya Institute of Technology, Bangalore in 2013. His area of interest is on characterization of construction materials, Traditional organic lime mortar, Heritage structural conservation.