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The Baclayon Church (Bohol) Debris of Mortar: A Geomaterial Dimension of Philippine Cultural-Historical Church

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ABSTRACT. Heritage is the totality of tangible and intangible inherited identity in a society. Different churches are tangible ancestral heritage with its unique architectural framework and artistic elegance. Baclayon church as heritage is one of the earliest historical-cultural structures by the Spanish conquistadores with its unique baroque architectural design. Structural materials include adobe, coral stone, bricks and limestone with organic adhesive additive like eggs, oil and viscous plant extracts. In October 15, 2013 a 7.2 earthquake devastated the province of Bohol with Baclayon as one of the most affected. This research explores the Baclayon church: the historical-cultural testimony and mineralogical components of its mortar. The methodology used is a complementary study on narrative from archival data files and geomaterial characterization of different fragments. From the debris, samples with code BCB1, BCB2 and BCB3 are analyzed for its chemical components using Shimadzu FT-IR and ED-XRF. From this analysis, the major mineralogical bulk is calcite. Based from FT-IR spectra, the adsorption peaks are located in the calcite range point and in complement with the ED-XRF. The greater volume of calcite is 95.139 % (BCB1), 95.131 % (BCB2) and 94.190 % (BCB3). Aggregate materials like silicates are limited to a minimal proportion. Mineralogical constituents include strontium, silicon, potassium, iron, sulfur, zinc, copper, nickel, lead, phosphorus, magnesium and lutetium. Traces of inorganic barium and lithium as well as organic amine group related to protein compounds are identified using the Shimadzu spectral library as reference. The mineralogical composition indicates that the binder is a hydrated mortar containing lime particles. Lime mortar is a primary material for the conservation of historical-cultural structures which are significant for aeration and water absorption.

Keywords: church, heritage, mortar, Fourier Transform Infrared (FT-IR), Energy Dispersive X-ray Fluorescence (ED-XRF)

1. INTRODUCTION

Ancestral heritage is characterized by the spectrum of conceptual endowment of linguistic configuration, architectural structures, tangible artistry of ceramics, paintings and artworks, and abstract concept and memoir (Umass Amherst Center, 2019). Historical-cultural churches in the Philippines are endowed treasures from the Spanish influence in the orient with more than a hundred structures built in every country's ritual space and sanctuary. Colonial Spanish era from 1565 until 1898 produced Spanish architectural significance: *la templo espiritual* or *iglesia* (simbahan or church) connecting *campanario* (carillon belfry), *convento* (parish priest residence), *escuela* (parochial school), and *fuerza* or *fortaleza* (fortified citadel); the public architecture of *casa real* (royal house) and *tribunal* (court), the *farola* (lighthouse observatory), the vernacular *casa de hormigon y madera* or *bahay na bato* (concrete and wooden residences), and the *puente* (structural arch masonry) (nlpdl.nlp, 1981).The birth of the Philippine colonial architecture started from the landing of Miguel Lopez de Legaspi exploration (1565). They established the *siudad* (city) and constructed religious sanctuary and *fuerte* (fort). In 1571, they overtook and explored Manila for the beginning of colonial *pueblo* architectural projection.

Cultural-Historical Churches' Masonry. The architectural design is based from the Spanish-Mexican flamboyant baroque found in the plaza area, churches, convent, bell tower and fort. These structures are made from adobe, coral stone, bricks and limestone usually from the introduction of volcanic stone quarries (Palafox, 2014). Stonework and masonry began with a Jesuit missionary, Antonio Sedeno in 1581 who introduced this form of construction method in the Philippines with his familiarity and expertise on quarrying, stone masonry, arches design and dimensional survey (Villalon, 2014).

2. METHODOLOGY

Heritage Profiling. Archival research is a process of compiling existing abstracts, materials and facts documented in the past. It is a theory and philosophy of facts' production, development and acquisition in connection with oral and written thesis (Tesar and Arndt, 2019). Archival evidences are historical-cultural data for deposition of ancient or late circumstances for proceedings or retrospection. They are broad spectrum of manifestation, proceedings and materialization from particular or diverse phenomenon to monumental incident (Van Gardener, 2007).

Figure 1: Fragments from the debris of Baclayon Church

Baclayon Church has a background full of events, milestone and development of historical-cultural mantra of Bohol. Archival documentation of Baclayon Church is a narrative, unstructured, feasible, and uses non-ethnographic mechanism.

Geomaterial Characterization. The *theory of restoration* by Cesare Brandi (1963) resolved that any historical-cultural components should be rehabilitated on its authentic properties and appearance (Mangay et al, 2018). The importance of geomaterial characterization of historical-cultural mortars was to prepare prospective restoration of mortars with identical peculiarity of the sample (Dalto et al, 2018).

Sample fragments (see Figure 1) were obtained from the debris of the collapsed structure of the Baclayon Church in Bohol which was very much devastated by the 2013 earthquake. These

were non-destructive and non-abrasive method of mortar collection. The mortar samples were analyzed by Shimadzu IRTracer-100 Fourier Transform-Infrared spectroscopy and Shimadzu EDX 800P Energy Dispersive X-ray Fluorescence. This FT-IR with excellent reactivity and accuracy had Lab Solutions IR software with wide range data base of different continuum spectra. The EDX 800P had immense perceptibility LED lamp and PCEDX Navi software (Shimadzu 2019).

3. RESULTS AND DISCUSSION

Heritage Profiling. The Philippines' earliest religious sanctuary is the Baclayon's Church of Our Lady of the Immaculate Conception. It is one of the finest secured and erected Jesuit religious sanctuary in addition to Agustinian Recollects' structural exterior and architectural masonry. Jesuit Fr. Juan de Torres and Fr. Gabriel Sanchez from Cebu were the pioneer Spanish missioner or *doctrineros* in Baclayon dating back on November 17, 1596. When Baclayon became a parish in 1717, the church was built with local restricted manual labor or *obras pias* had been enforced. The construction materials were corals from the nearby seas and volume of albumin from eggs as an adhesive plastering materials (Hellingman, 2013).

On October 15, 2013, the devastating 7.2 magnitude earthquake in Bohol busted different centuries-old churches with the Immaculate Conception of Virgin Mary Parish or Baclayon Church among them. The church underwent enormous destruction with ruined veranda and carillon (inquirer.net, 2013).

Geomaterial Characterization Using Fourier Transform Infrared (FT-IR). Three fragments of Baclayon Church debris (see Figure 1) during the October 15, 2013 earthquake with 7.2 magnitude had been characterized using Fourier Transform Infrared (FT-IR). Different traces of compounds were approximately identified with a standard reference from the Shimadzu library of different spectra of chemical compounds.

Table 1: Traces of Compounds using FT-IR with Standard Reference

Spectrum Adsorption Range (cm^{-1})			Standard Reference (Shimadzu)	
BCB 1	BCB 2	BCB 3		
769	670	611	$BaCO_3$	Profile 9 File: BACO3.DX
750	814	832	$CaCO_3$	Profile 7 Calcium Carbonate Transmission
685	625	628	Li_2CO_3	Profile 10 Lithium Carbonate Transmission
650	652	642	K_2CO_3	Profile 9 Potassium Carbonate Transmission
626	607	590	Melamin	Profile 22 Polymer2 Melamin
603	none	none	Chimassorb944LD	Profile 69 Polymer2 Additive
602	none	none	Chimassorb944LD	Profile 80 Polymer2 (Polymeric)
600	590	591	D_Additive7	Profile 69 Polymer Additive (Chimassorb 944LD)
580	none	none	Epoxy	Profile 42 Polymer2 Epoxy Adhesives
572	584	585	Epoxy	Profile 45 Polymer2 Epoxy Resin
567	none	none	D_Epoxy6	Profile 42 Polymer2 Epoxy Adhesives

Based from the Shimadzu references, the traces of inorganic compounds (see Table 1) were barium carbonate, lithium carbonate, calcium carbonate, potassium carbonate, calcium nitrate, and

potassium nitrate. Also, from the Shimadzu references, organic components were identified as a polymerized organic compounds believed to be additive and adhesive organic character such as: melamin, achromatic translucent compound of heterocyclic organic structure and higher content of nitrogen, a complementary character of protein (Rogers, 2019). Other organic compound identified was a polymer additive with identical characteristic of Chimassorb944LD, higher value of oligomeric interfering amine light stabilizer (HALS) (SpecialChem, 2018). Another organic compound identified was the epoxy adhesive and polyvinyl alcohol. Epoxies are polymerization of two reacting compounds: the resin and the hardener. Polyfunctional primary amines mold primary group of epoxy hardeners. Polyvinyl alcohol is water-soluble synthesized polymer and forming carbon-carbon linkages. IR absorption spectra of major and inorganic components of the mortar fragments are shown in Figure 2, Figure 3 and Figure 4 with corresponding Table 2. Studies on calcite IR spectra had corresponding absorption value at 1796, 1430, 874 and 713 cm^{-1}. The quartz IR spectra had corresponding absorption value at 1874, 1072, 794 and 695cm^{-1} (Dalto et al, 2018).

Figure 2, Figure 3 and Figure 4: FT-IR spectra of Fragment BCB1, BCB2 and BCB3, respectively.

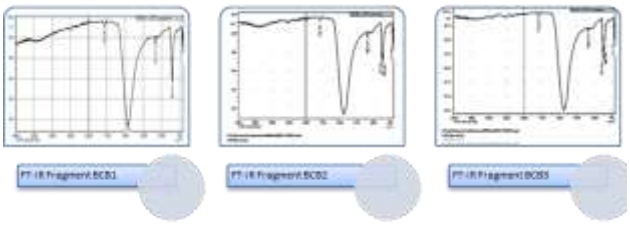

Table 2: Tentative adsorption spectra of major components of mortar debris

Adsorption spectra position (cm^{-1})	Sample debris BCB1 (cm^{-1})	Sample debris BCB2 (cm^{-1})	Sample debris BCB3 (cm^{-1})
C-O plane bending (Ravinsakar et al, 2010)	711.73	711.73	711.73
C-O weak bands (Sathya et al, 2012)	854.47	856.39	856.39
C-O out of plane bending (Cayme et al, 2016)	none	871.82	873.75
Si-O stretching (Velraj et al, 2012)	1082.07	1082.07	1082.07

From Figure 2, the IR adsorption spectra of fragment BCB1: 711.73 cm^{-1}, 854.47cm^{-1}, 1456.26 cm^{-1}, 1469.76 cm^{-1} and 1786 cm^{-1} for calcite and 1082.07 $cm^{-1}$for silicate IR spectra. From Figure 3, the sample fragment BCB2 has corresponding IR spectra 711.73 cm^{-1}, 856.39 cm^{-1}, 871.82 cm^{-1}, 1440.83 cm^{-1} and 1791.87 cm^{-1} for calcite and 1082.07 cm^{-1} for silicate. With Figure 4, the Baclayon church fragment BCB3 has FTIR spectra of 711.73 cm^{-1}, 856.39 cm^{-1}, 873.75 cm^{-1}, 1440.83 cm^{-1} and 1791.87 cm^{-1}.

Geomaterial Characterization using Energy Dispersive X-ray Fluorescence (ED-XRF). Mortar lime as the ultimate geologically extensive structural materials was used comprehensively by coastland community wherein mollusk and shale are extremely sufficient. It was one of the earliest constituent of primeval historical flooring, brickwork, exterior canvas, plaster coating, and architectonic engraves. Interest of mortar was important date back in 8,000 BCE along the transcontinental region and 4000 years ago in earliest American civilization (getty.edu, 2011). Lime is a basic and natural component generally the surface sedimentary rock containing calcium carbonate. It is a fundamental binder forming the silicates and aluminates of calcium. From Table 2, sample fragments from Baclayon church debris had elemental calcium composition of 95.14 % (BCB1), 95.13 % (BCB2) and 94.19 % (BCB3).

Elemental Composition	Fragment BCB1 (%)	Fragment BCB2 (%)	Fragment BCB3 (%)
Calcium (Ca)	95.139	95.131	94.190
Strontium (Sr)	2.603	2.675	3.097
Silicon (Si)	1.183	1.106	1.279
Potassium (K)	0.406	0.388	0.386
Iron (Fe)	0.347	0.129	0.182
Sulfur (S)	0.183	0.020	0.106
Zinc (Zn)	0.061	0.026	0.026
Copper (Cu)	0.031	0.025	None
Nickel (Ni)	0.029	0.017	0.003
Lead (Pb)	0.012	none	none
Magnesium (Mg)	none	0.483	0.601

Table 2: Elemental Composition of Baclayon Church debris using ED-XRF

Aside from lime mixture, masonry mortar includes the ingredients of granular earth materials of sand (0.125 to 0.25 mm) and amount of water. The utmost natural component of finer sand is silicates in a configuration of quartz. Silicates or silicon dioxide is a mineral salt of anions of silicon and oxygen combining with metal ions as components of earth rocks. They are inert material and fillller to accumulate volume. They inhibit mortar reduction and fracture of binder. From Table 2, the component analysis of silicon of Baclayon church debris were 1.183 % (BCB1), 1.106 % (BCB2) and 1.279 % (BCB3). Other elemental components with respective amount in Table 2 were strontium, potassium, iron, sulfur, zinc, copper, nickel, lead, phosporus, magnesium and lutetium as part of minerals in earth's crust.

4. CONCLUSION

Mortar is a complicated structural material with researches on different ancient procedural technique. The plasticity and workability of the mortar mixture is dependent on the elemental components, texture and mixture. The conclusive mortar output of lime, fine sand and water is waterproof and eradicate shrinkage cracking. Calcite in lime in its higher composition and lesser amount of quartz cannot gain strength and durability to withstand destruction of the natural calamities (earthquake and typhoon). From the mineralogical investigation, the majority on highest proportion is calcite with a range of 94-96 %. Other components are limited and more minerals are only traces in proportion. Organic content and inorganic salts are detected in traces using Shimadzu library of spectral adsorption peaks of different compounds as reference in FT-IR instrumentation.

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