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The Mechanical Properties and Absorption of Artificial Hydraulic Lime

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Abstract
This article is aimed to research the mechanical properties and Absorption on an Artificial Hydraulic Lime (AHL).Natural hydraulic lime (NHL) is a material widely used to repair and restore historic buildings. In Korea, although lime mortars have been used as important building materials for thousands of years, the sharing of information and technology with other countries has been relatively inactive. While not recognizing the suitability of NHL as a repair material, undesirable materials such as Portland cement have often been selected due to their high strength, ease of use, and hydraulicity, but unfortunately, this has resulted in the irreversible damage of existing elements, especially in historic masonry structures. This study aims to produce an artificial hydraulic lime for the repair and conservation of historic masonry. A Hydraulic Lime (HL) that meets the British standards with its compressive strength and flexural strength. And can set under wet conditions . Artificial hydraulic lime for the sustainable preservation of architectural heritage.
Keywords: *Compressive strength, Flexural Strength, architectural heritage,Artificial hydraulic lime, Absorption.*

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I. INTRODUCTION

The service life of ancient structures is mostly incorporated with Hydraulic Limes. In the past most cases, restoration interventions had employed cement and polymer-based materials, which resulted in advancing the deterioration state, since harmful by-products have induced severe damage to the adjacent stone blocks.Lime has had a long history of use for building in Britain [1]. The Romans employed it in their construction operations and it was used extensively in mortars and surface finishes from then until the nineteenth century when patent cements, such as Portland cement, were introduced. The use of lime declined in the twentieth century, but increasingly it has been recognized that hard, cement mortars are unsuitable for use on old buildings, and lime is enjoying a revival [2]. However, much of the skill and knowledge needed to use lime successfully had nearly died out so when lime began to be more widely demanded in conservation work there was often a lack of suitably experienced specifiers and skilled craftsmen [3]. The practical techniques required for the use of lime can be mastered by anyone with good building skills or a practical aptitude, but for successful use of lime it is essential to understand how the material works and to follow basic guidelines when using it. This thesis explains how hydraulic lime works, why it is of such benefit in maintaining and repairing historic buildings [4]. It will be useful to owners of historic buildings who lack the confidence to use lime themselves or who would like to know more about it before instructing a builder to use it. It may also be handy for builders who are unfamiliar with lime, and serve as a reminder for those who have not used it for years [5].

Importance of Lime-Based Materials

Traditionally knowledge and experience on the manufacture and use of lime mortars were handed on verbally to the next generation. Rules for lime mortars would therefore reflect regional variations in the composition of raw materials. A system of widespread small-scale production resulted in significant variation in the quality of lime mortars. This inconsistency contributed to its replacement by cement mortars in the latter half of the twentieth century. In recent decades modern research interest in lime mortars has been driven primarily by conservation work. Modern hydraulic lime mortars are sourced from a small number of industrial suppliers, providing a more consistent supply chain than traditionally available, which has facilitated research characterizing material performance. Lime-based materials are important historic building materials that have contributed significantly to the development of human culture and civilization They have been used to construct historic buildings and infrastructure for over 10,000 years [1,2]. Lime mortar was not widely used until it was adopted by the Greeks and later the Romans around the 1st millenniumThe most advanced form, Portland cement, has led to the construction and expansion of cities in a short period of time, in which the hydraulicity of this binder as well as its high strength and fast strength development are involved. Hydraulicity is defined as the property of a dry powder that can harden in water or when mixed with water.

Raw Materials

The raw material for hydraulic lime is a limestone which contains calcium carbonate together with a proportion of clay. Such a limestone is known as argillaceous. Most limestones for hydraulic lime production contain between 15 and 35 per cent silica together with alumina - two important constituents of clays. Most argillaceous limestones are somewhat grey or blue in color. They can also be distinguished by having a dull surface which does not sparkle in sunlight when broken. As with all types of limestones, argillaceous limestones will fizz when a few drops of dilute hydrochloric or sulphuric acid are put on them. Marlstone - a soft limestone that is common in some areas, is often a suitable raw material for producing hydraulic lime. Most limestones used for hydraulic lime production vary in properties such as clay content and type of clay minerals present in a single deposit. This results in the production of a lime with significant variation in properties such as strength and setting time, even with a high level of quality control during production. Allowance for such a variation should be made in using the lime.Pure" limes are not hydraulic and are also known as non-hydraulic, air or putty limes. They will not set in water, rather curing over a long period by slowly reabsorbing carbon dioxide from the atmosphere. They may be available from a limited number of suppliers as the aforementioned highly caustic quicklime, the more widely distributed typical bagged hydrated lime or occasionally as a lime putty in sealed containers. Usually when the chemical composition of limestone is discussed, it is presented as CaCO3 or calcium carbonate. However, both calcium and magnesium are alkaline earth metals having similar properties and found in lime. Sea creatures in particular can metabolize a certain percentage of magnesium as a double carbonate with calcium for shells if there aren't enough calcium ions in the water. Over geologic time huge sedimentary deposits of these magnesium containing limestones have formed around the globe. Although most all limestone contains some magnesium, anything less than 5% will produce a calcitic or "High Calcium" lime.Dolomitic limestones are very common and limes prepared from them historically required special preparation, especially for plastering. For traditional lime kilns, larger particles of quicklime typically remained that might take weeks or even months to slake. Lime expands when it slakes and if this delayed expansion happened after the lime was applied to the wall as a plaster it would cause "pops" that could totally ruin a plaster finish. As dolomitic limes take longer to slake than calcium limes, they were more susceptible to this problem. The traditional solution was to slake the lime all the way to putty several months before work was to begin. With industrial means of production that include grinding and screening processes as well as forced hydration under increased barometric pressure there is little cause for concern with delayed hydration or risk of plaster pops. Most commercially available hydrated lime can be slaked overnight and used the next day although the longer it sits the creamier and more pleasant it is to work with.

Properties of Hydraulic Lime

Natural hydraulic lime (NHL) mortars are widely used for restoration works due to their good compatibility with the substrate material in terms of physical, chemical, and mechanical properties. Regarding their mechanical characterization, there is still a need for further understanding of their fracture behavior and the influence of their dosage methodology on the mechanical properties. Thus, this chapter focuses on the mechanical characterization of NHL mortars, such as flexural, compressive, and splitting tensile strengths, elastic modulus, and fracture energy. Moreover, the influence of the composition and production process on such properties was studied as well. Furthermore, the loading rate effect on the fracture behavior was also presented. The results show that NHL mortars have shape and size effect on the compressive strength. In addition, NHL mortar is rate sensitive, mainly due to the viscous effects caused by the presence of free water in the porous structure.Natural hydraulic lime (NHL) is a binding material formed by burning of argillaceous or siliceous limestones with reduction to powder by slaking with or without grinding [1].From a mineralogical point of view, it is mainly composed of portlandite ($Ca(OH)_2$), dicalcium silicates (C_2S), gehlenite (C_2AS), and small amounts of tricalcium silicates (C_3S). Tricalcium aluminate (C_3A) and tetracalciumaluminoferrite (C_4AF) can be present as well. Moreover, calcite ($CaCO_3$) can also appear in NHL as a result of a slight carbonation (reaction with carbon dioxide from the air) of portlandite during storage. When mixed appropriately with water and aggregates, NHL produces mortars which are able to harden and gain strength with time. As a hydraulic material, NHL mortars have the property of setting and hardening under water and reacting with carbon dioxide from the air (carbonation) .The use of NHL mortars prevails presently for restoration works due to their good compatibility with the substrate material in terms of physical, chemical, and mechanical properties. That is to say, NHL mortars interact quite well with stones and blocks of masonry walls; the interventions with the materials are durable in time and do not originate spalling of the stones. Moreover, NHL mortars are more appropriate than air-hardening or lime pozzolana ones when the early strength gain is essential [6]. Furthermore, NHL mortars are eco-efficient as they require low amount of energy during their production process and absorb CO_2 from the air while carbonating. Knowledge on the mechanical properties of mortar is crucial to ensure a good performance of masonry structures In general, NHL mortars are well investigated in terms of compressive and flexural strengths. Nevertheless, there is still a need for the further understanding of the mechanical behavior of NHL mortars under quasi-static and dynamic loading conditions, especially for the latter. In this chapter, under quasi-static loading condition, an advanced mechanical characterization of NHL 3.5 mortars has been performed, such as elastic modulus, fracture energy, splitting tensile strength, and compressive and flexural strengths. Particularly, compressive strengths from prisms and cylinders were compared to study the size and shape influence. Moreover, the effects of dosage and production process on these properties were analyzed as well. Under dynamic loading condition, NHL mortar beams were tested at various loading rates (loading-point displacement rates) by using a servo-hydraulic testing machine, from the quasi-static one, 5.0×10^{-4} mm/s, to rate sensitive ones, 5.0×10^{-1} mm/s (intermediate loading rate) and 1.6×10^{1} mm/s (fast loading rate).

The properties of hydraulic limes depend on their chemical composition, the manner in which they have been burned, and on the manner, they have been slaked or hydrated. The composition of hydraulic limestone includes the amount and types of inorganic impurities whichgive the hydraulic lime its hydraulicity. These impurities include silica, alumina, and ferric oxide. The properties of hydrated hydraulic lime can be compared to those of a mixture of Portland cement with a corresponding proportion of hydrated lime. The material is easy to use and flows freely under the trowel, but sets and hardens more slowly than Portland cement and does not attain as great a strength as a lime-free Portland mix.l.The hydraulic limes with high compressive strength contain 65% lime, 10 - 12% alumina, and 23 - 25% silica, which approximates the same proportions as a typical Portland cement. The setting of hydraulic lime is a similar process to that of Portland cement, but because there is less free lime in Portland cement, more strength is produced in the Portland.Hydraulic lime mortars are increasingly used for new building. The bond strength of lime mortar masonry has not yet been quantified; however, this is one of the most important properties of the hardened mortar because it determines strength, durability and use of masonry. Bond deterioration reduces the compressive strength of a wall and can destroy its tensile or shear strength; and a defective bond can lead to water ingress and subsequent damage. Bond strength also impacts structural behavior: masonry is strong in compression, however, it is weak in flexural tension, and the reason for this weakness is the bond interface between mortar and masonry.As a result, allowable compressive stresses in building codes are substantially larger than allowable flexural tension stresses, and this limits the use of masonry as a structural element. Therefore, improvements in the bond strength would enhance use of masonry. Furthermore, structurally, masonry systems rely on a good bond in order to maintain integrity under exposure under wind suction or pressure, the masonry relies on the strength of the bond in order to transfer lateral stresses throughout masonry segments and support the flexural tensile stresses generated. Research has been undertaken into the bond strength of Portland cement and cement/lime mortarsIt is assumed by the building industry that Portland cement and cement/lime mortars bond well with building units, whereas lime mortars, are not always considered capable of developing sufficient bond.This is a misconception partially due to a lack of knowledge and insufficient research on lime-mortar bond strength. For example, outstanding research works such as the Smeaton Project have identified bond strength as crucial but have not measured the property. The objective of this paper is to quantify the bond strength of natural hydraulic lime mortars of different hydraulic strengths (NHL2, 3.5 and 5), and investigate the effect of the mortars' hydraulicity, water retention and water content on the strength of the bond. Water content determines both the mortar's workability and its initial flow; these properties were also measured and correlated to the bond strength. This study contributes to better characterize natural hydraulic lime mortars in order to enhance their use in building, and establishes relationships between bond strength, hydraulicity, water content, workability and water retention. These relationships can assist the production of mortars designed to reach high bond strengths, and this would improve the quality and performance of hydraulic lime mortars in construction.

Artificial Hydraulic Lime

The production of artificial hydraulic limes is discussed as a possible alternative to natural hydraulic lime. It deserves some consideration, because there is the issue of variability of the constituents of hydraulic limestone as a function of natural variability in the beds. The idea of having a consistent product is worth consideration. One artificial lime that Bumell mentions is General Treussart's artificial hydraulic lime; which involved the mixing 5 measures of chalk by volume to 1 of clay, then the paste is burnt. The lime was then slaked with water in which potash and soda were mixed in proportions necessary to bring the solution to 5% acidity.calcination of a mixture of the rich lime and the alkali silicate in the proportions of from 10-12 of the latter, to 100 of the former. Both must be very finely powdered and well mixed or otherwise the reaction would be incomplete, and subsequently solidification would produce a disintegration of the mass.The artificial hydraulic limes did not attain the same degree of hardness or the same compressive strength as the natural hydraulic limes of the same class. Of the latter, those which were obtained from the closest grained and densest lime stones, were reported to be the most resistant. They were used in preference to the artificial cements. This did not apply (lack of compressive strength) to the over-burnt limes, because Portland cement attained both great tensile and compressive strength.Searle also discussed the topic of artificial hydraulic lime. He believed that artificial hydraulic lime could be produced by mixing slaked lime and clay in the proper proportions. It also could be made by mixing soft limestone or chalk with clay, grinding them together to form a paste, then molding them into rough bricks and burning them. The proportions of clay and lime or limestone to be used were dependent upon the composition of each, but the addition of one-part clay to four parts of rich lime was typical. Also, if argillaceous limestone was enriched with a purer limestone or diluted with clay, the proportions of each could be adjusted so as to produce a lime having the desired properties.In addition, it was also possible to produce hydraulic lime by under-burning a mixture of limestone and clay or shale, however such a lime may contain a large proportion of wholly inert.material. A mixture of limestone and clay, artificial or manmade. must contain more than 80% calcium carbonate, or the product will contain too much uncombined lime and silica. Searle concluded that the best hydraulic limes are natural, made from rock containing the ingredients in the right proportions, - an artificial hydraulic lime cannot produce as uniform a mixture as nature.

Hydraulic lime was an important cementitious material before the arrival of Portland cement but it is little used now, except in conservation work. Production of good hydraulic lime is as much a craft as a technology, even more than ordinary lime but, with the decline in use of hydraulic lime, there are few skilled producers left and new producers often need to learn the required skills from scratch. Hydraulic lime hardens partly by reaction with water and so differs from other types of lime which harden by chemical reaction with carbon dioxide in the air. Hydraulic lime has properties intermediate between ordinary lime and Portland cement but is produced in a similar way to ordinary lime. In addition to containing calcium hydroxide, the chemical which makes up ordinary lime, hydraulic lime also contains calcium silicates similar to the main cementitious components of Portland cement. A cement with properties similar to hydraulic lime can also be obtained by mixing ordinary lime with a pozzolanic material. Hydraulic lime can be made stronger than ordinary lime and can be used in some applications for which ordinary lime is not suitable, particularly where water is present.

The durability characteristics both in construction or restoration of monuments are dependent on the use of proper mortar. Results obtained and several studies reported in the literature. It is more practical to propose a lime based mortar with aggregates originated from the limestone in order to have an excellent compatibility with the chemical properties. The study suggests that mortar seems to have similar mechanical strength properties and is found to be compatible to that of tuffeau stone mainly if lime-aggregate reaction is taken into consideration over a longer period of time. . The hydraulic properties need to be further investigated more mainly with respect to permeability and diffusion variations. However, imbibition results indicate mortars using low percentages of lime (≤ 20%) are compatible with tuffeau. Moreover, this study demonstrates clearly that there is no difference in the behavior of the mortar composed of hydraulic or non-hydraulic lime. However, these tests have been carried out on few samples and so more samples must be tested to for better understanding of differences in the behavior between the two tested limes. Microscopic observation and mercury porosimeter investigation studies are necessary for different samples of mortar in order to follow and to compare the microstructure and the pore size distribution changes with lime type and proportion. Furthermore, aging tests including thermo-hydromechanical cycles under real environmental conditions are necessary to evaluate the performance (deterioration and durability) of the proposed mortar in order to confirm the compatibility of the conceived mortar (based on hydraulic or non-hydraulic) with the tuffeau.

Table 1. shows Lime & Cement - Classification & Properties

Lime Classification	Active Clay Materials	Setting Time in Water	Slaking Time	Expansion
Fat Lime - white color	< 6% (typically < 2%)	no set (putty)	very fast	considerable
Lean Lime - white, off-white color	< 12% (typically < 6%)	no set (putty)	fast	large (e.g.x 2)
Magnesian (dolomitic) - white, off-white color	typically < 10%	no set (putty)	very slow	varies
Feebly Hydraulic - off white, pale gray color	< 12%	< 20 days	slow	slight
Moderately Hydraulic - pale gray, buff color	12 - 18%	15 - 20 days	slow	slight
Eminently Hydraulic - gray brown color	18 - 25%	2 - 4 days	very slow	slight
Natural Cements - light to very dark brown color	30 - 40%	12 hours	very slow	slight

Advantages of Hydraulic lime Based mortars

Lime mortar is often said to be able to 'breath'; it is vapor permeable meaning it allows water, in vapor form, to pass through it. Depending on relative pressure differentials moisture movement can be from inside to outside or vice-versa. Vapor permeability is beneficial to masonry joints and surrounding fabric as it prevents build-up of damp, reducing risk of condensation problems (e.g. mould) and avoiding salt and frost damage. Some advantages include:

- **low strength and stiffness**

Natural hydraulic lime mortar is generally much softer compared to cement-based materials. Its low strength and stiffness, along with autogenous healing, means it morereadily accommodates building movement.

- **Environmentally friendly:**

Lime mortar is commonly regarded as having lower environmental impact than cement mortar. This is based on lower embodied carbon of lime (cradle to gate: 0.74 kgCO2/kg) compared to 8 cement (cradle to gate: 0.83 kgCO2/kg) (Hammond & Jones 2011). It not only absorbs potentially damaging carbon dioxide from the atmosphere, but the amount of energy required to produce it is less than is required for the production of cement and as it can be produced on a small scale, there is less impact on the local area.

- **Improved performance compared to air lime**

Compared to air lime, hydraulic lime mortars have higher initial strength, the ability to set underwater and improved frost resistance.

- **Workability**
- **Functionality:**

Natural hydraulic lime is available in a range of strengths (NHL 2, NHL 3.5 and NHL 5), giving it a wider range of applications to different types of masonry and different weather conditions.

- **Easy handling**

Unlike lime putty or slaking quicklime, natural hydraulic lime is supplied as a powder, like cement, which makes transport, storage and proportioning much easier and more accurate [7,9,10].

Mechanical properties of Artificial Hydraulic Lime.

Experimental

A hydraulic lime is made from a limestone that either naturally contains or has artificially introduced some form of amorphous silica in the burning process. This amorphous or "free" silica fuses with some of the quicklime to form a clinker, a cementitious compound. That cementitious clinker is what makes the lime hydraulic, meaning that it will set with the addition of a certain percentage of water.However, freshly burned hydraulic lines are often very caustic as well so they are typically slaked also. Enough water is added to quench the quicklime but less than required to initiate the hydraulic reaction, the result being that most hydraulic limes sold commercially are both hydraulic and hydrated.

To produce an AHL we use a mix proportions of ratio 1:2 (Binder Sand ratio). We Mixthe materials using suitable mixing machines. The materials for this test included

- Sand size 1.18
- White Cement
- Tap Water
- Mixing machine.
- Slag
- Hydrated Lime
- Calcium carbonate
- Calcium Oxide

Table 2. Mix proportion I grams

	Cement	Slag	Hydrated Lime	Calcium carbonate	Calcium Oxide	Water	Sand	Sand size
	270	75g	202.5	101.25	101.25	413.5	1500	1.18

Strength Test Procedure

1. Placed the prepared mix in the steel cube mould for casting.
2. Once it sets, after 24 hours remove the cube from the mould.
3. air curing for stipulated time of 7 days, 14 days and 28 days.
4. As mentioned the specimen was kept for air curing for 7 or 14 or 28 days.
5. Test specimens for flexural strength, then test for compressive strength.

Fig 1.strength test machine

Flexural Strength

Before carrying out the compressive strength test, this study firstly conducted the flexural strength test. The specimen was 40mm and the depth was 40mm while its supported length was 100mm. The results of flexural and the compressive tests on concrete expressed as a modulus of rupture which is denoted in MPa were calculated as follows:

$$\sigma_f = \frac{3FL}{2bd^2} \quad (1)$$

Table 3.Flexural strength test results

Days at Test	Force for specimen 1 in (KN)	Force for specimen 2 in (KN)	Force for specimen 1 in (KN)	Average force in Kilo newton (KN)	Flexural Strength in mega pascal (Mpa)
HL5-7d	1.32	1.47	1.24	1.34	3.1406
HL5-14d	1.38	1.52	1.36	1.42	3.3281
HL5- 28d	1.78	1.21	1.66	1.55	3.6328

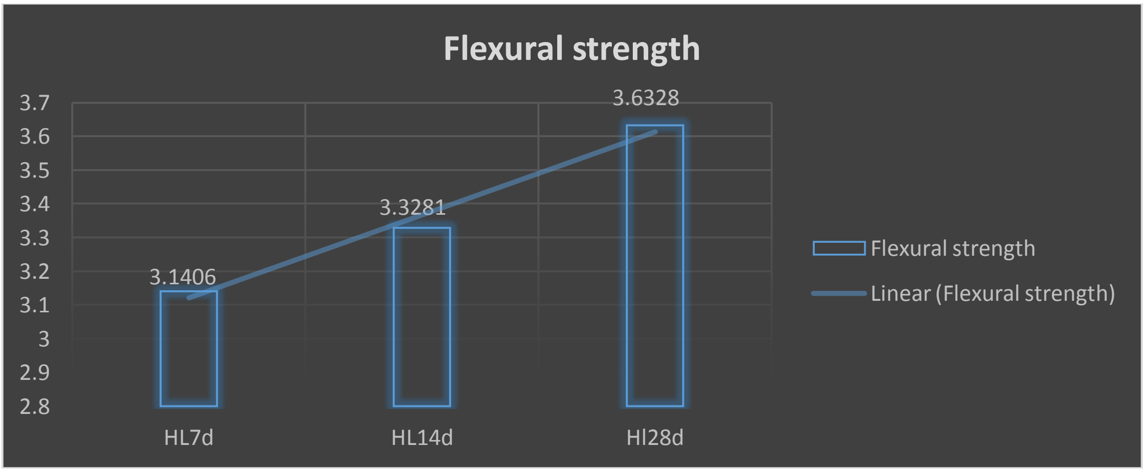

Fig 2. HL5 Flexural strength Results graphical presentation.

The graph above graphically compares the flexural strength of the Hydraulic Lime concrete determined at 7 days, 14 days and 28 days respectively. It appears that there are three groups of results. The first group is where the flexural strength is very low implying that the concrete in not strong, the second group is moderate, implying that after 14 days the concrete is stronger than it was at day 7 and the third group implies that the concrete is strongest at day 28.

Compressive strength

Table 3.Compressive strength test

Days at Test	Force for specimen 1 in (kN)	Force for specimen 2 in (kN)	Force for specimen 3 in (kN)	Average force in Kilo newton (KN)	Strength Mpa
HL5-7d	18.59	18.84	19.28	18.903	11.8144
HL5-14d	21.57	21.66	21.44	21.557	13.4731
HL5-28d	23.52	22.62	22.45	22.863	14.2893

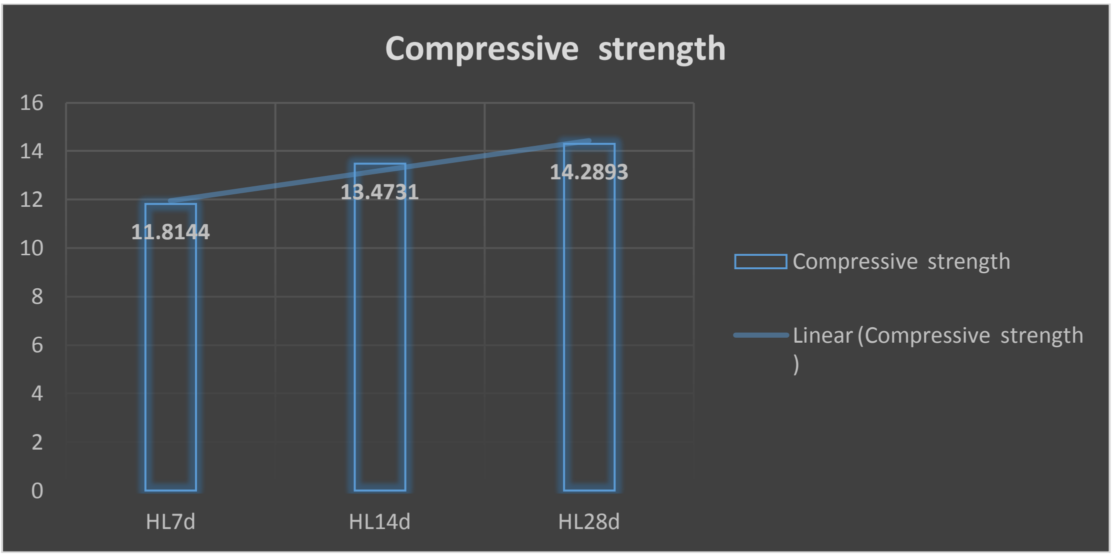

Fig 3. HL5 Compressive strength Results graphical presentation.

$$\sigma = \frac{F}{A} \qquad (2)$$

The hydraulic lime after 7 days was divided into three specimen and tested for compressive strength, specimen 1 needed the force of 18.59kN to compress, specimen 2 needed the force of 18.84Kn to compress and specimen 3 needed the force of 19.28kN to compress. Therefore, on average the force needed to compress the complete specimen on day 7 was 18.903kN. And therefore the compressive strength was found to be 11.8144Mpa. The same was repeated for 14 days and 28 days.

Compressive strength test Results graphical presentation.

The compressive strength of Hydraulic Lime concrete was determined at 7 days, 14 days, and 28 days, as shown in the graph below. There appear to be three groupings of findings. The first group has a very low compressive strength, meaning that the concrete is weak; the second group has a moderate compressive strength, implying that the concrete is stronger after 14 days than it was at day 7, and the third group has the strongest concrete at day 28. No clear justification could be offered for such observation due to a lack of valuable information and the test's unpredictability. Regardless, the overall pattern from the data is clear: the compressive strength of concrete improves

Comparing the Compressive strength Results to the standard measurements.

The table below shows the standard acceptable compressive strength for hydraulic lime and natural hydraulic lime. The table contains the type of building lime with the corresponding compressive strength.

Table 4. BS EN Standard measurements

Type of building lime	compressive strength Mpa	
	7 days	28 days
HL2 and NHL2	-	2 to 7
HL3.5 and NHL3.5	-	3.5 to 10

HL5 and NHL5	2	5 to 15^{a}
HL5 and NHL5 with a bulk density lower than $0.90kg/dm^3$ is allowed to have a strength up to 20Mpa		

Going by the standard measurements, and comparing with the results of the compressive strength of this research, the type of building lime produced by this study is HL5 and HL3.5 because the compress strength is at day 7, 14 and 28 are all within the acceptable range of 5 to 15^{a}. This is in line with the research aim of producing Artificial Hydraulic Lime (AHL) which can be used for ancient buildings repairing.

SEM Test

SEM analysis of the studied mortars cured for 28 days. Left side is SEM image of the sample magnified at 24.0mmx2.00k and right side is the Zoom of the same image magnified at 24.0mmx4.00k.

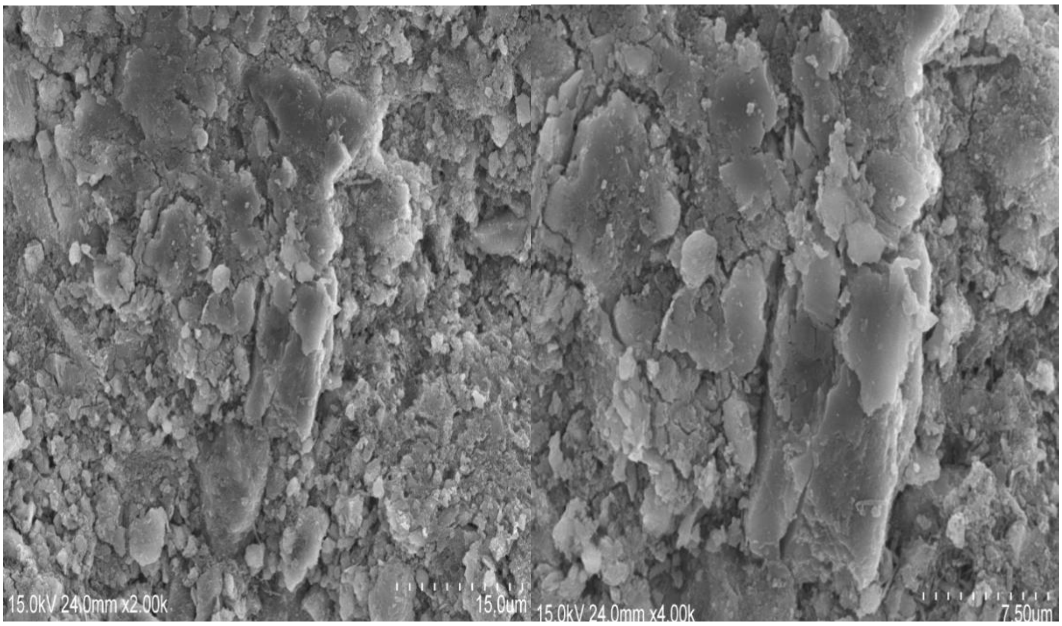

Fig 4. HL5 SEM Test

Element Analysis

The energy dispersive spectroscopy (EDS) technique is mostly used for qualitative analysis of materials but is capable of providing semi-quantitative results as well. Typically, SEM instrumentation was equipped with an EDS system to allow for the chemical analysis of features being observed in SEM monitor. Simultaneous SEM and EDS analysis is advantageous in failure analysis cases where spot analysis becomes extremely crucial in arriving at a valid conclusion [11]. Signals produced in an SEM/EDS system included secondary and backscattered electrons that are used in image forming for morphological analysis as well as X-rays that are used for identification and quantification of chemicals present at detectable concentrations. The detection limit in EDS depended on sample surface conditions, smoother the surface the lower the detection limit.

Elemental analysis of surfaces in SEM was performed using energy dispersive spectroscopy (EDS), which measures the energy and intensity distribution of X-ray signals generated by the electron beam striking the surface of the specimen. The elemental composition at a point, along a line, or in a defined area, could be easily determined to a high degree of precision. Elemental maps were often used to locate areas rich in elements present in concentrations greater than 1% by weight. The electrons penetrated a depth of 0.02–1.0 µm into the sample and so care was taken to prepare samples appropriately

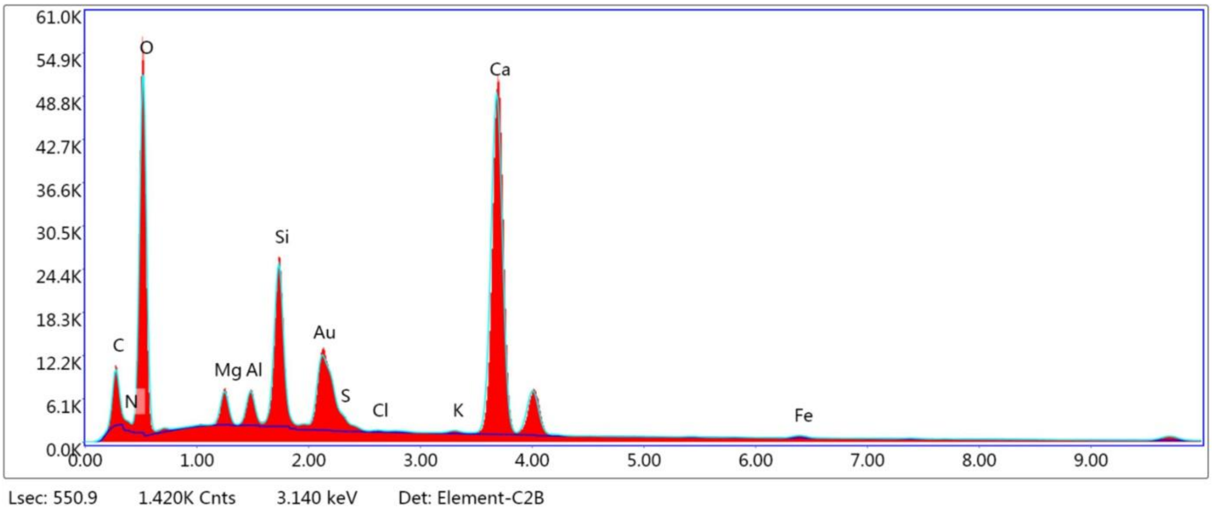

Fig 5: HL5 weight spectrum test

eZAF Smart Quant Results

Element	Weight %	Atomic %	Error %
C K	3.89	7.60	8.80
N K	0.71	1.19	20.31
O K	41.36	60.65	9.45
MgK	1.42	1.37	6.54
AlK	1.29	1.12	5.42
SiK	6.05	5.05	3.64
AuM	7.42	0.88	5.48
S K	0.70	0.51	6.73
ClK	0.02	0.02	76.34
K K	0.20	0.12	14.08
CaK	36.11	21.13	2.05
FeK	0.83	0.35	11.35

Fig 6. HL5 Element, Weight, Atomic and Error Percentage

Absorption Of AHL

Absorption testing is a popular method of determining the water-tightness of concrete. A water absorption test measures the amount of water that penetrates into concrete samples when submersed.The maritime code BS 6349 specifies that water absorption should not exceed 3%, or 2% in critical conditions such as highly aggressive chloride or freeze–thaw exposure, when tested in accordance with BS 812-2. The drying shrinkage test in BS 812 Part 120 is limited to aggregates with water absorption <3.5%.

Permeability height can be measured through soaking testing, and results about this are given in the analysis below.

The figure below shows the initial weight of the Hydraulic Lime weighed at 7days, 14days and 28days respectively.

Table 5. weights in intervals of the Hydraulic Lime sample.

	ABSORPTION														
	1(INTIAL)	1min	2min	4min	6min	8min	10min	12min	16min	20min	25mn	36min	49min	60min	24hrs
AHL 7d	241.7	254.2	260.9	268.1	271.9	273.4	273.6	273.5	273.4	273.5	273.7	273.76	273.6	273.7	274.7
AHL 14d	252.8	263.8	269.8	275.4	279.8	282.1	283.3	283.8	284.5	284.9	285.3	285.6	285.6	286.3	286.8
AHL 28d	246.7	256.7	263	269.1	272.7	275.1	276.3	276.9	277.5	277.8	277.9	278	277.9	277.9	278.8

	ABSORPTION													
	1	2	4	6	8	10	12	16	20	25	36	49	60	24HRS
Hl 7d	5.171700455	7.943732	10.92263	12.49483	13.11543	13.19818	13.15681	13.11543	13.15681	13.23955	13.26438	13.19818	13.23955	13.65329
Hl 14d	4.351265823	6.724684	8.939873	10.68038	11.59019	12.06487	12.26266	12.53956	12.69778	12.85601	12.97468	12.97468	13.25158	13.44937
Hl 28d	4.053506283	6.607215	9.079854	10.53912	11.51196	11.99838	12.24159	12.4848	12.6064	12.64694	12.68747	12.64694	12.64694	13.01176

Fig 7.Absorption test results

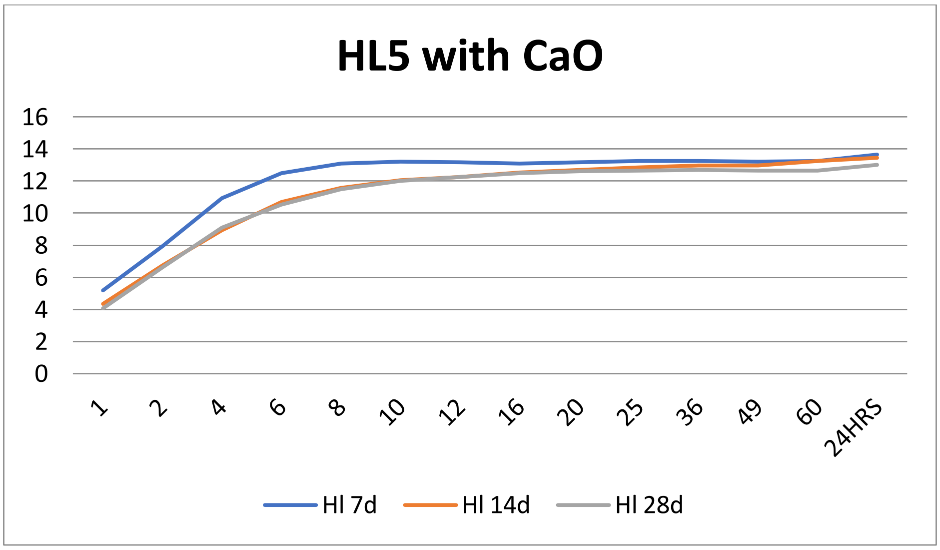

Fig 8.Absorption test for AHL 5

In the Hydraulic Lime with calcium in figure 4.5 above, it can be seen that penetration height increased apparently with time within 8 to 10 minutes for HL7d. similarly, the penetration height increased or absorption rate increase in the initial stages for both HL14d and HL28d. For different curing methods, penetration height was not the same in the initial stages until beyond 12 minutes when they became uniform. HL14d and HL28d were constant after 10 minutes . In contrast, the samples cured on condition of HL14d and HL28d showed the lowest penetration height, while the samples of curing condition of 7days presented the highest one which is HL7d. The absorption test for AHL indicated that different curing conditions caused different absorption rate of samples.

Relations between Water Absorption and Strength

After being cured for 28 days, compressive strength was measured and presented in this chapter. The rule of thumb is that Samples cured in air condition (°C, RH 90 ± 5%) show highest strength, while those cured in air condition (°C, RH 60 ± 5%) have lowest strength. Although the specimens differ in surface water absorption, there is little difference in internal water absorption[12]. Furthermore, the high surface water absorption only decrease compressive strength of concrete. The whole strength of concrete depends on both surface and internal structures. Therefore, strength of concrete cannot be evaluated by water absorption. Although the specimens differ in surface water absorption, there is little difference in internal water absorption. Furthermore, the high surface water absorption only decreased compressive strength of cover concrete[13]. The whole strength of concrete depends on both surface and internal structures. So, strength of concrete cannot be evaluated by water absorption**.**

II. DISCUSSION

The sustainable preservation of architectural heritage is particularly important because it is not just for use and residence, it is also an asset of humankind to be passed down intact to the next generation. In reality, this heritage is deteriorated by various environmental factors and even people. In a situation like that in South Korea, where knowledge about traditional building materials and techniques has been almost forgotten due to rapid industrialization and social change, the preservation of historical buildings based on unfounded customs and a lack of scientific knowledge can seriously deteriorate the historical buildings' structural safety and durability. Furthermore, it is also important to understand the concept of preventive conservation.

Based on the above facts only, it is still early to assert the use of hydraulic lime in Korea. However, this possibility can be suggested due to the current study being in early stages. This suggestion also raises the need for continuing research to find additional evidence.

III. CONCLUSION

Going by the standard measurements, and comparing with the results of the compressive strength of this research, the type of building lime produced by this study is HL5 and HL3.5 because the compress strength is at day 7, 14 and 28 are all within the acceptable range of 5 to 15^{a}. This is in line with the research aim of producing Artificial Hydraulic Lime (AHL) which can be used for ancient buildings repairing and the mechanical properties of AHL manifested in the experiments that were conducted in this study.

In absorption test curing conditions can greatly affect the water absorption of concrete. Based on the curing conditions in this paper, the concrete which was exposed to air curing with calcium exhibited low water absorption. In addition, surface water absorption was higher than internal water absorption regardless of curing conditions. Both of surface water absorption and internal water absorption had no clear relationship with compressive strength in the tests with CaO, which indicated that the strength cannot be simply evaluated by water absorption.

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