Research for Historic Mortars and their durability, in the Old City of Akko

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- **Goals:** Point out researches and intervention plans on mortars that occurred over the past few years and evaluate their efficiency in the present time.

- **Work Methodology:** Research through written documentation and photo documentation; practical work through workshops and analysis *in situ* of the mortar (physical condition, binding materials.)

- **Content:** Brief Description of problems in Akko (environment factor and human factor), brief description of Kurkar Stone; Type of mortars used in Akko, Mortar in usage; previous Researches and studies; Conclusion and recommendations.

1. BRIEF INTRODUCTION TO MORTAR

A mortar is a material resulting of the intimate mixture of sand grains, a binder (lime, cement, etc.) and water. The properties and characteristic of the mortars mainly depend on the nature of the binder component. That is the reason for which, its evolution with time has been much related to the development of artificial cementitious materials. So, with the consolidation of the Roman civilization the use of lime mortars was generalized and extended. Since the 18th century, hydraulic binders partially begun to replace the lime. These new materials hardened more quickly and developed higher mechanical strengths. In the 19th century, the invention of Portland cement revolutionized the world of building materials, completely displacing the use of lime in all type of civil and military constructions.
Throughout the centuries mortars, as constructive element, have had a double mission: on one hand to make the link between other materials (fundamentally rocks or bricks); and on the other hand to cover and protect the surfaces of columns, walls, facades ... They have been, at a certain extent, the skin of the building.
It is obvious that these functions are vital for the conservation of the "monument", and they reveal the importance of these materials in the Historical Heritage.
Some characteristics of the mortars (mainly those related with the heterogeneous composition and high porosity) can affect its durability by making them easily attackable for external agents, and so to contribute to the instability of materials in contact with them. Some of those characteristics can stimulate the access of polluting agents that act as initiators of the deterioration of the materials that mortars are protecting or binding.
All this clearly explains the role of the mortars in the conservation of the buildings and constructions of the Heritage.

1.2. MORTARS IN/OF Old AKKO

The interest for the systematic study of ancient mortars in the Old City of Akko is not recent. First deep researches arise in early 90s in order to establish an investigation strategy of ancient mortars as well as of mortar's repairs.
IAA, conjointly with international institution (mainly from Italy) carried out researches and analysis on petrography, sandstone, mortars, plasters, soils, and foundations, in the Citadel and in Crusader and Ottoman buildings.

2. The Kurkar Stone

Kurkar is a type of sand stone derived from sediments typically found along the Mediterranean coast of Israel.
Its composition is based on silt and finely graded quartz sand and its texture, shape and strength are determined by the sedimentary components within.
The deterioration of the mortar applied in the Kurkar walls can be accelerated due to the high level of porosity of the stone itself.

3. Type of Mortars and their usage in Akko

Around the Old City, it is possible to find several types of mortars and their different functions in the buildings.

Mortar based on Lime: Lime mortar is a type of mortar composed of lime, an aggregate such as sand, and water. It is one of the oldest known types of mortar, dating back to the 4th century BC and widely used in Ancient Rome and Greece. The binder used in lime mortars is calcium hydroxide which produces $CaCO_3$ when carbonated (compound responsible for the hardening of the material). Limes can be classified into 2 groups: hydraulic lime and air lime. Non-hydraulic lime is primarily composed of calcium hydroxide generally greater than 95%).

Building limes can be classified into two groups:

1. Air lime: It is fundamentally constituted by calcium oxide (unslaked lime) and/or hydroxide (slaked lime).

2. Hydraulic lime: The hydraulic limes consists predominantly of calcium silicates, calcium aluminates and calcium hydroxide.
The main difference between the air and the hydraulics lime, resides that in the first case the addition of water has the only objective of facilitating the mixture of the components and placing the mortar, but it does not intervene in any chemical reaction. The process of hardening of the mortar carried out with air lime, takes place for the reaction of the Ca(OH)2 with the atmospheric CO2 producing CaCO3. This product provides, to the lime mortar its physical, chemical and mechanical properties.
Concerning hydraulic lime mortars, in this case the addition of water, besides favouring the fluidity of the slurry, it intervenes in chemical reactions with silicates and aluminates (both present in the raw materials) generating the formation of hydrated compounds that confer the mortar some different properties to those obtained in the case of the air limes.

The main properties and characteristic of lime mortars are the following:
1. Low mechanical strengths, due to the low affinity of the calcite and quartz crystal, as well as to the weak linkage among the calcite particles.

2. Easy workability, due to the slow process of setting (carbonation) that depends on the environmental conditions.

3. High capacity of deformation (low module of elasticity). It allows the material to absorb small movements of the adjacent materials.

4. High permeability to water and water vapour.

5. Low resistance to the freeze-thaw cycles.
No presence of soluble salts, what avoids the processes of dissolution-crystallisation of the salts, and therefore the appearance of efflorescence and subflorescences.

These properties can be relatively modified by altering the process of production of the mortar, the type of aggregate, the aggregate/binder and water/binder ratios, etc.

Mortars based on Portland Ciment Binders: The portland cement binder is a finely ground artificial product, of inorganic and mineral nature, which main property, when mixed with water, is to form a slug that harden and gives stable products with time.
The raw materials used in the manufacture of Portland cement are mainly constituted by four mineral oxides: lime, silica, alumina and iron oxide.
The main characteristics of a hydrated portland cement related with its chemical composition are:

1. Stability of volume. With the hydration process a mortar undergoes shrinkage due to a volume decrease of the hydrated cement phases. Additionally, the so called hydraulic retraction is also produced; it happens for the quick evaporation of the water of the plastic mass.

2. Resistance to the chemical aggression. If the mortar has been carefully elaborated (well compacted, no cracks, low porosity, appropriate binder/water ratio, etc.) then it will have good durability.

3. High mechanical strengths.

4. Heat of hydration. The hydration reactions of Portland cement phases are exothermal. The fast development of heat in the system can lead to a quick evaporation of water which could give place to the formation of cracks in the mortar.

Pozzolana Mortar: Pozzolana is a fine, sandy volcanic ash which finely ground and mixed with lime, acts like Portland cement and makes a strong mortar.

The addition of a pozzolana will decrease setting times and increase strength of lime-based concretes, mortars and renders. It is able to produce hydraulic cement which has the ability to set under water.

The main properties of lime plus pozzolana mortars are the following:

1. Relatively low mechanical strength, although superiors to those in lime mortars.

2. Certain capacity of deformation (low module of elasticity).

3. Low resistance to the adverse climatic conditions.

4. Scarce presence of soluble salts.

5. Lower permeability to water than lime mortars.

Mortar based on clay binders: Because of its plasticity when mixed with water (in certain proportions and) firmness, clay binders are added very often to the Mortar. This type of material is widely use in Old Akko both for internal and external walls.

3.2 Technical Function of the Mortars

The application of the mortars in Akko is mainly done under two systems: application of facings, which encloses walls, and masonry, which deals with bedding, pointing, sealing and repairing.

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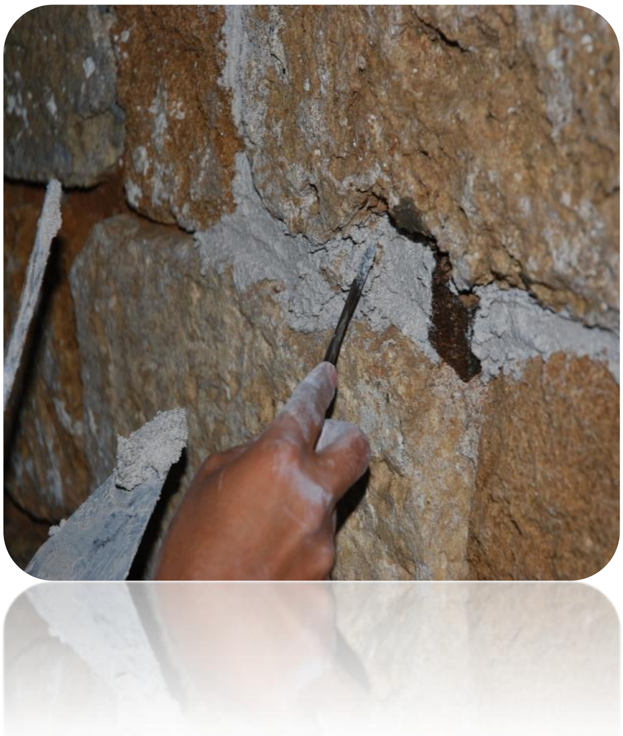
The mortar composition for wall coating is mainly based on lime and crushedstone.



Repointing, sealing and repairing are is directly related to obvious sign of deterioration, such as disintegrating mortar, cracks in mortar joints, loose stones, damp walls, or damaged plasterwork.

First stage of intervention process is to resolve the cause of the deterioration such as leaking roofs or gutters, differential settlement of the building, capillary action causing rising damp, and extreme weather exposure. Only then does the mortar restoration process starts.

4. REASONS FOR MORTAR DECAY

Mortar deterioration occurs through different chemical, physical, mechanical, biological processes. Very often, more than one alteration mechanism takes place simultaneously and also frequently chemical processes or biological processes, etc., have physical or mechanical effects; it means that is quite difficult to establish a classification of the deterioration mechanisms of mortars.

Sited by the sea and exposed to winds coming from all fronts, Akko suffers of intemperate weather changes during the year.
So, the main problems that occur in Akko are:

Water: Pure waters (proceeding from the condensation of the fog or of the water vapour) and the soft waters (rain water or melted snow and ice) contain little or nothing of calcium. When these waters get in contact with the hardened mortar they spread through the porous system of the material and dissolve the hydrated phases which are rich in calcium.

Salt: The crystallization of soluble salts in the porous system of the mortars frequently produces deterioration. Salts are produced from the ions that water have extracted from altered rocks, floors, mortars, concretes, bricks, etc. The aerosols of marine environment and atmospheric pollutants of industrial or urban environment, contribute to the deposition of salts in those mentioned materials.
Given the porous nature of building materials, the ions penetrate and circulate through them as diluted solutions. A salt will crystallize when the water evaporates and the activity of ions in the solution overcomes that of saturation; but also when the relative humidity of the atmosphere in the surroundings of the material is inferior to that of equilibrium of a saturated solution of this salt. In this way, in a porous system containing accumulated salts, they will crystallize and they will be dissolved again depending on the relative humidity of the air.

Thermal Variations: The temperature variations can produce dilations and contractions in the material and so creating tensions. The rendering of walls with several layers of renders of different characteristics was an usual practice in the past and it still is at present. Frequently these different materials possess different thermal expansion coefficients. Under certain circumstances tensions can take place in the materials, giving place to cracking and breaking down of the layers.

Air Pollution: The degree of interaction between atmospheric SO2 and the mortars binder is a complex factor very difficult to be determined, as there exist a lot of variables affecting that process and influencing it at different levels (the concentration of the gas in the atmosphere, the direction of the wind, the intensity of the rain, etc). Concerning the effect of SO2 on the mortar, this is a function of the capacity of self protection of said material (nature of the binder, microstructure, porosity and permeability).
In general, it is accepted that the interaction mechanisms between atmospheric SO2 and building materials take place through very well known processes of dry deposition and wet deposition (acid rain).

Deficient intervention actions: Improper restorations by applying incompatible materials help to accelerate the process of the deterioration of the mortar.

5. THE RESEARCHES

The CFERML Project – 2007

In 2007, IAA conjointly with IVBC carried out an intense research and rehearsals on mortar and plaster.

According to the report, many experiments, pilot projects, laboratory tests and small researches have been accomplished, with few positive results.

Plus, the technological engineering-conservation-techniques have been mostly found and applied: instead of cement mortar and concrete, it has been a return to lime mortar, wood and stone. Instead of stiff static modern systems of steel and concrete, it has been a return to wood, arch and volts static systems.

15 samples of mortar were taken out from Medieval and Ottoman buildings and the analysis result are the following:

- **Medieval Mortar** is strong and stiff. No hydraulic elements found in the binders. The coal within seemed sporadic and not part of the mixture.

- **Ottoman Mortar** is weak and soft, but more elastic.

Facades Plaster Research Project-2008

Norbert Hoepfer performed a full research on plastered and non-plastered walls in Ottoman Buildings.

The study provided the following result: non plastered walls (with the Kurkar stone exposed) are absorbing salt and water from the air and rain.

Plastered or covered walls with dense or strong materials like concrete, cement plaster or acrylic paints and coats are having problems with the transport of water and salt.

In both situations, the conclusion is that the Kurkar Stone is reaching a high level of deterioration (the stones are falling into sand).

Regarding the historic plaster and pointing in Acre, the project indicates that was mostly done with quick lime and sea sand (grey-yellowish) or coal ash (grey-black). The final coat was made with lime putty and fibers (white). The remnants of this were mostly very wet, salty and stick very weak to the wall (bad adhesion).

Plaster Detached from the Wall - 2007

Uri Buri Plaster System

Over the past 20 years, Uri Buri has dedicated his time to improve the Mortar and Plaster Systems in Old Akko. In 2007 it was developed the *Plaster detached from the Wall* system, which has been considered the ultimate achievement to hold the plaster on the wall for a long time.

The Uri Buri Plaster System was developed especially for plastering difficult walls such as damaged walls with high level of moisture, salt, or chemical content. It is also adapted to walls with quantities of salt, close to the sea; suitable for walls with mixed materials and cracked walls. The system provides durable protection of walls against weather and environmental influence.

Uri Buri Plaster System is assembled on an existing wall with or without plaster: the first layer detaches the new plaster from the old wall. This layer incorporates a reinforcement layer of crossing ribs covered on the front side with geotechnical fleece. This fleece separates the air space provided by the crossing ribs and the plaster. The second layer, consisting of crossing ribs, functions as a plaster holding system. Both layers are made out of a resistant plastic material, which is connected to the wall with plastic dowels. The plaster adheres to the crossing ribs by surrounding it, which creates a stable and overlapping plaster layer. The thickness of the plaster is 15 mm or more.

Final Results taken out from the system: so far the plaster and the mortar hold steady in external walls. Regarding the interior walls, the system doesn't seem efficient. Moisture problems haven't been 100% solved inside the buildings, therefore the plaster starts to crack and fall.

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CONCLUSIONS:

- Mortar deterioration is rapid;
- Substitution of the mortars is done more often than its preservation;
- Previous Researches haven't reach any effective solution to Preserve in long term Historic Mortars.

RECCOMENDATIONS:

- Cleaning methods for the elimination of salts;

- Interaction of atmospheric pollutants with mortars. Influence of mortar characteristics on the velocity of interaction;

- Development of new formulations. Use of organic admixtures. Insisting in a correlation ship between properties of mortars and mechanical and micro structural characteristics;

- Development of analytical and instrumental methods that permit a correct evaluation of conservation treatments. Performance of accelerated ageing tests;

- Identification of mortar through an inter-laboratory test.

Ideal Mortar for Restoration and Conservation:

Easy workability;

Rapid and reliable setting in dry and wet environments;

Slow shrinking during setting;

Soluble salts content as low as possible;

BIBLIOGRAPHY

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SOURCES

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