Plaster Architecture

Essay

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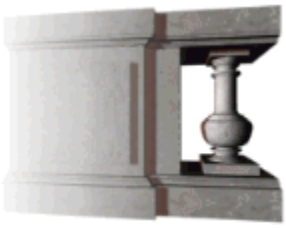

The materials used in 19th and 20th century plasters: from lime and gypsum to Portland cement

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- 1. Historical background

The earliest plasters known to us were lime-based. Around 7500 BC, the people of 'Ain Ghazal in Jordan used lime mixed with unheated crushed limestone to make plaster which was used on a large scale for covering walls, floors, and hearths in their houses. Often, walls and floors were decorated with red, finger-painted patterns and designs. In ancient India and China, renders in clay and gypsum plasters were used to produce a smooth surface over rough stone or mud brick walls, while in early Egyptian tombs, walls were coated with lime and gypsum plaster and the finished surface was often painted or decorated. Modelled stucco was employed throughout the Roman Empire. The Romans used mixtures of lime and sand to build up preparatory layers over which finer applications of gypsum, lime, sand and marble dust were made; pozzolanic materials were sometimes added to produce a more rapid set. Following the fall of the Roman Empire, the addition of marble dust to plaster to allow the production of fine detail and a hard, smooth finish in hand-modelled and moulded decoration was not used until the Renaissance. Around the 4th century BC, the Romans discovered the principles of the hydraulic set of lime, which by the addition of highly reactive forms of silica and alumina, such as volcanic earths, could solidify rapidly even under water. There was little use of hydraulic mortar after the Roman period until the 18th century.
Plaster decoration was widely used in Europe in the Middle Ages where, from the mid-13th century, gypsum was used for internal and external plaster. Hair was employed as reinforcement, with additives to assist set or plasticity including malt, urine, beer, milk and eggs. In the 14th century, decorative trowelled plaster, called pargeting was being used in South-East England to decorate the exterior of timber-framed buildings. This is a form of incised, moulded or modelled ornament, executed in lime putty or mixtures of lime and gypsum plaster. During this same period, terracotta was reintroduced into Europe and was widely used for the production of ornament. In the mid-15th century, Venetian skilled workers developed a new type of external facing, called marmorino made by applying lime directly onto masonry.
In the 16th century, a new highly decorative type of decorative internal plasterwork, called scagliola, was invented by stuccoists working in Bavaria. This was composed of gypsum plaster, animal glue and pigments, used to imitate coloured marbles and pietre dure ornament. Sand or marble dust, and lime, were sometimes added. In this same century, the sgraffito technique, also known as graffito or scratchwork was introduced into Germany by Italian artists, combining it with modelled stucco decoration. This technique was practised in antiquity and was described by Vasari as being a quick and durable method for decorating building facades. Here, layers of contrasting lime plaster were applied and a design scratched through the upper layer to reveal the colour beneath. The 17th century saw the introduction of different types of internal plasterwork. Stucco marble was an artificial marble made using gypsum (sometimes with lime), pigments, water and glue. Stucco lustro was another a form of imitation marble (sometimes called stucco lucido) where a thin layer of lime or gypsum plaster was applied over a scored support of lime, with pigments scattered on surface of the wet plaster.
The 18th century gave rise to renewed interest in innovative external plasters. Oil mastics introduced in the UK in this period included a "Composition or stone paste" patented in 1765 by David Wark. This was a lime-based mix and included "oyls of tar, turpentine and linseed" besides many other ingredients. Another "Composition or cement", including drying oil, was patented in 1773 by Rev. John Liardet. A similar product was patented in 1777 by John Johnson.
In 1774, in France, a mémoire was published on the composition of ancient mortars. This was translated into English as "A Practical Essay on a Cement, and Artificial Stone, justly supposed to be that of the Greeks and Romans" and was published in the same year. Following this, and as a backlash to the disappointment felt due to the repeated failure of oil mastics, in the second half of the 18th century water-based renders gained popularity once more. Mixes for renders were patented, including a "Water Cement, or Stucco" consisting of lime, sand, bone-ash and lime-water (Dr Bryan Higgins, 1779).
Various experiments mixing different limes with volcanic earths took place in the 18th century. John Smeaton (from 1756) experimented with hydraulic limes and concluded that the best limes were those fired from limestones containing a considerable quantity of clayey material. In 1796, Revd James Parker patented Parkerís "Roman Cement". This was a hydraulic cement which, when mixed with sand, could be used for stucco. It could also be cast to form mouldings and other ornaments. It was however of an unattractive brown colour, which needed to be disguised by surface finishes.
Natural cements were frequently used in stucco mixes during the 1820s. The popularisation of Portland cement changed the composition of stucco, as well as mortar, to a harder material. The development of artificial cements had started early in the 19th century. In 1811, James Frost took out a patent for an artificial cement obtained by lightly calcining ground chalk and clay together. The French Engineer Vicat in 1812-1813 experimented with calcining synthetic mixtures of limestone and clay, a product he introduced in 1818. In 1822, in the UK, James Frost patented (another?) process, similar to Vicat's, producing what he called "British cement". Portland cement, patented in 1824 by Joseph Aspdin, was called so because it was supposed to resemble Portland stone. Aspdinís son William, and later Isaac Johnson, improved the

production process. A product, very similar to modern Portland cement, was available from about 1845, with other improvements taking place in the following years.
Thus, after about 1860, most stucco was composed primarily of Portland cement, mixed with some lime. This made it even more versatile and durable. No longer used just as a coating for a substantial material like masonry or log, stucco could now be applied over wood or metal lath attached to a light wood frame. With this increased strength, it ceased to be just a veneer and became a more integral part of the building structure. Early 19th century rendered façades were colour-washed with distemper; oil paint for external walls was introduced around 1840.
The 19th century also saw the revival of the use of oil mastics. In the UK, patents were obtained for "compositions" in 1803 (Thomas Fulchner), 1815 (Christopher Dihl) and 1817 (Peter Hamelin). These oil mastics, as the ones before them, also proved to be short-lived.
Moulded or cast masonry substitutes, such as cast stone and poured concrete, became popular in place of quarried stone during the 19th century. However, this was not the first time "artificial stone" had been widely used. Coade Stone, a brand name for a cast stone made from fired clay, had been developed and manufactured in England from 1769 to 1843 and was used for decorative architectural elements. Following the closure of the factory in South London, Coade stone stopped being produced, and the formula was lost. By the mid 19th century manufacturing centres were preparing cast stones based on cement for use in buildings. These were made primarily with a cement mix often incorporating fine and coarse aggregates for texture, pigments or dyes to imitate colouring and veining of natural stones, as well as other additives. Also in the 19th century, various mixtures of modified gypsum plasters, such as Keene's cement, appeared. These materials were developed for use as internal wall plasters, increasing the usefulness of simple Plaster of Paris as they set more slowly and were thus easier to use.

- 2. Materials

The terms "plasterwork", "plaster", "stucco" and "render" are often used interchangeably, but have regional variations. In this paper, "stucco" is taken to be a composition that can be applied to the whole or part of a building and can be used equally for a plain covering or for mouldings and ornaments. Compositions range from lime and aggregate mixes (with other additives) to gypsum mixes, to cement and sand renders.
Up until the late 1800's, stucco, like mortar, was primarily lime-based, consisting of hydrated or slaked lime, water and sand, with straw or animal hair often included. Interior stucco was generally made with gypsum, marble dust and glue. It was often moulded into ornamental shapes and polished to a marble-like finish. During the 17th and 18th centuries, elaborate painted figures and ornaments were made with stucco. After ca 1860, as already stated, Portland cement largely replaced lime for external renders.

2.1 Binders

Lime plaster is composed of calcium oxide (lime), obtained by heating calcium carbonate (limestone, marble, chalk and shells) in a kiln to between 900°C and 1200°C. Carbon dioxide (and any water) is driven off leaving anhydrous calcium oxide or quicklime, sometimes described as unslaked lime or, misleadingly, as lump lime. Quicklime soaked in water changes to calcium hydroxide or slaked lime. When dried and ground to a fine powder, it is called hydrated lime or lime hydrate. The addition of highly reactive forms of silica and alumina, such as volcanic earths, ash or rock (such as tuff or pumice), brick dust, or ground iron slags, produces a hydraulic set. Here, the lime does not set by carbonation and can solidify rapidly even under water. Materials that induce this effect are called pozzolanic additives. Hydraulic lime can also be made by calcining limestones such as lias, which have a high silica content.
Gypsum plaster has been used for renders and mortars since the time of the ancient Egyptians. It is also used for moulds, sculptures and castings. The plaster is prepared by heating gypsum minerals (calcium sulphate dihydrate) to about 150°C to partially remove the chemically bound water, thus producing calcium sulphate hemihydrate, the main component of Plaster of Paris. When this is mixed with water, it converts to the hydrated calcium sulphate that rapidly sets to an impenetrable solid, generating heat and expanding slightly. Its rapid setting necessitates great skill in handling when used as a wall plaster. The set and workability of gypsum plaster are controlled by various additives. As it is slightly water soluble, its use in temperate climates was largely confined to interior decoration, as a finish for walls and ceilings, although it was occasionally used, on its own or mixed with lime, for external work such as pargeting or as an infill in timber-framed buildings. In such situations the surface had to be worked to a smooth finish and protected by effective roofing. It was often protected by linseed oil paint. Today, gypsum has to a great extent replaced lime for internal plasters. It is preferred because it hardens faster and has less shrinkage than lime. Lime is generally used only in the finish coat in contemporary stucco work.
In the 19th century, various mixtures of modified gypsum plasters were patented in the UK as artificial marbles, many of which were cast into slabs for interior decoration. These included Martin's cement and Keene's cement, both patented in the 1830s, and Parian cement, patented in 1846. These involved the modification of gypsum plaster through heating and chemical treatments to produce a material which reliably set more slowly than gypsum but more rapidly than lime. This obviated the problems of difficulty in working and delay before decoration could be carried out.
Portland cement was patented in 1824 by Joseph Aspdin. It was made by crushing and calcining a "hard limestone", mixing the lime with clay and grinding the product into a fine slurry with water. This was fired, broken into lumps and fired a second time. Although this material was hydraulic, it was not as strong as modern cements because it was manufactured at lower temperatures. In the late 1830s Isaac Johnson discovered that overburnt lumps from the kilns produced a stronger, more reliable product with a slower set. His process, patented in 1838, involved heating limestone or chalk to 1300-1500°C, which converted it to quicklime. This then reacted with the clay to form clinker that was ground and mixed with gypsum to retard the set. For use it was mixed with water. The set occurs through the formation of calcium silicates and calcium aluminates in the film. These react with water to from starburst-shaped particles that interlock to give

cement its strength. Modern ordinary Portland cement is a hard, grey, impervious material that is mixed with sand for use as a mortar and a render.
Terracotta, a decorative building material made by moulding and/or modelling clay and firing to obtain a hard, durable product, was a very popular substitute material in the late 19th and early 20th centuries. It simulated the appearance of intricately carved stonework, which was expensive and time-consuming to produce, and could be glazed to imitate a variety of natural stones, from brownstones to limestones, or could be coloured for a polychrome effect. The clay used was generally fine-grained to accept detail; sand or crushed fired clay, called grog, were added to reduce shrinkage and distortion during firing.

2.2 Additives

Stucco often contained substantial amounts of mud or clay, marble or brick dust, or even sawdust. An array of other additives ranged from animal blood or urine, to eggs, keratin or gluesize (animal hooves and horns), varnish, wheat paste, sugar, salt, sodium silicate, alum, tallow, linseed oil, beeswax, and wine, beer, or rye whiskey. Additives, or admixtures, were usually added to enhance or modify characteristics such as curing time, plasticity, colour, or volatility. Also, without additives the plaster was weak and prone to shrinkage and cracking. Often aggregates were added to increase the strength and decrease porosity.
Inorganic additives were used to increase hardness, resistance, and durability and to retard setting. Sand was added as filler, primarily to reduce shrinkage, increase strength, improve working properties and generally enhance performance. Most natural sands are at least 98% silica. Fine aggregate produced by crushing rock, gravel, or slag commonly is known as manufactured sand. Marble powder was sometimes added as an aggregate because it permitted the rendering of fine detail.
The aim of adding organic substances was either to improve the workability, to harden the mass, to retard setting, or to influence the mechanical properties of the mass. Organic materials (blood, glue, casein) and weak acids (citric acid, boric acid) can act as retardants. Accelerants are compounds that speed up the rate of hydration and thereby cause the mix to set or harden sooner. In medieval work gypsum plaster was frequently added to lime as an accelerator of set. Additives to provide water-repellency, such as waxes, fats and oils, or to entrap air and thus improve the set, such as urine or beer, were traditionally used. For hand-modelled ornament, gypsum was added, with a retardant such as glue, sour milk or wine, to allow a long working time; sugary materials reduced the amount of water needed and slowed down the setting time, and alcohol acted as an air entrainer. All of these additives contributed to the strength and durability of the stucco.
The appearance of much stucco was determined by the colour of the sand--or sometimes burnt clay--used in the mix, but often stucco was also tinted with natural pigments, or the surface whitewashed or colour-washed after stuccoing was completed. Brick dust could provide colour, and other colouring materials that were not affected by lime, mostly mineral pigments, could be added to the mix for the final finish coat. Stucco was also marbled or marbleised--stained to look like stone - by diluting oil of vitriol (sulphuric acid) with water, and mixing this with a yellow ochre, or another colour. As the twentieth century progressed, manufactured or synthetic pigments were added at the factory to some prepared stucco mixes.
Many formulations included the use of hair, jute, flax or straw as extenders. Animal hair gives the lime and sand greater toughness and cohesion; it has long been used as a binding material in lime and gypsum plasters. Ox hair was commonly used, but horse, goat, and even human hair were used as substitutes. The use of human hair was however rare because of its fineness and poor strength.

- 3. Examples of exterior plasterwork

Historic external renderings include a wide range of aggregates, binders and reinforcement. A simple classification includes types varying from very low strength daubs, usually applied in a single thick coat to backing of wattle or lath, to high strength renderings based on hydraulic cements and applied in two or more coats to brick or stone or lime based undercoats. Other types include low to medium strength renderings based on lime applied in two or more coats to backing of brick, stone, unbaked earth, wattle or lath; and medium strength oil mastics usually applied in one thin coat to brick, stone, or lime based undercoats but also used to model detail. Medium strength gypsum or lime/gypsum renderings in two or more coats on brick, stone or lath are also to be found.
Historic external stucco includes pargeting, sgraffito and marmorino. Treatments and coatings related to stucco in that they consist at least in part of a similarly plastic or malleable material include wattle and daub and "cob". These are regional variations on traditional mixtures of mud, clay, lime, chalk, cement, gravel or straw. Many are still used today.
Pargeting is external decorative plasterwork often incised or modelled with ornamental impressions or patterns made with a mould or comb. It consists of a tough lime plaster, made of lime putty or mixtures of lime and gypsum plaster, reinforced with ox hair, and with tallow sometimes added as a plasticizer and a water-repellent. The surface of the pargeting was frequently limewashed; occasionally linseed oil or wax was used as a protective coating. It was usually applied to timber-framed houses, especially during 15th and 16th centuries in south-east England.

Sgraffito is a decorative technique used in various media, also known as graffito or scratchwork, in which layers of contrasting colours are applied to a surface and a design is scratched through the upper layer to reveal the colour beneath. In the Renaissance, lime plaster, tinted with ash, was used as the under layer, and then covered with white lime plaster. Most sgraffito, especially two or three colour work, belongs to the 19th century. Then, the lowest, levelling layer usually consisted of Portland cement, above which a layer of cement coloured with earth pigments was applied. The final layer for indoor work was Parian cement; Portland cement was used externally. With all materials the layers were allowed to dry but not set completely before the design was cut in with an iron stylus or knife, used to peel away the upper layer. After the plaster or cement had set fully, areas of the design could be oil-gilded.

Marmorino (or marmorina) plaster is an external facing made by applying lime directly onto masonry or, more often, onto a layer of ground "Cotto", bound with air-hardening lime ("Cuogolo" lime), a semi-hydraulic type ("Negra" or "Brovada" lime). Finishes included treating with "Saponata", to which a further wax treatment was often added, or by applying one or two coats of linseed oil. In more exposed areas, additives such as metal grit (the so-called "Marogna" with a high Si and Mg content) were added.
The low strength wattle and daub is composed of interwoven sticks, twigs or branches plastered with clay, grease or mud. Wattle and daub construction was used for roofs, walls and fences, especially in the early 19th century. Traditional mixes also include mixtures of lime putty, sand and slurried cow dung, reinforced with chopped straw.
Cob (or clob) are walls composed of clay, earth, straw, lime and sand, mixed with water. Wet clay or chalk is tempered by the tread of horses with straw or reed. It is constructed without shutters in layers upon a stone or brick plinth. It is lifted wet on to walls, the surface is trimmed in position as it hardens. Shrinkage is considerable. It is usually covered with protective limewash or plastered.

- 4. Examples of artificial stone

Moulded or cast masonry substitutes, popular during the 19th century, were produced in a variety of materials made readily available by technology at this time. These products were cheap to fabricate and easy to use. Examples of some cast stone binders included clay, plaster, water glass, oxychloride cement, epoxy and Portland cement.
Cast stone is made with a cement mix often incorporating fine and coarse aggregates for texture, pigments or dyes to imitate colouring and veining of natural stones, as well as other additives. Examples include Frear stone, Victoria stone and Benedict stone. Various aggregates such as granite and other stone dusts, slag and crushed brick were used to produce a range of colours and textures. Cast stones were produced in many sizes and shapes, often with intricate patterns and tracery. Manufacturing centres were preparing cast stones based on cement (Pulham stone, Haddon stone) by the mid 19th century for use in buildings, statuary and decoration including balustrades, columns, architraves, arches and tracery windows. These fabricated units avoided expensive quarrying costs, and were versatile in representing either ornately carved blocks, plain wall stones or rough cut textured surfaces. The end result depended on the type of patterned or textured mould used.
Coade Stone was developed by Eleanor and George Coade in England and manufactured from 1769 to 1843. The formula, which was lost following closure of the factory, has only been deduced from recent analysis and experimentation. Analysis indicates the raw materials were ball clay from Dorset or Devon with the addition of 5-10% flint, 5-10% quartz sand, at least 10% grog and about 10% soda-lime-silica glass. The material was fired at temperatures between 1100°C and 1150°C over a four-day period, producing a hard, partially vitrified and durable material. Minimal shrinkage and distortion in the kiln, owing to the presence of the pre-fired grog, contributed to the materialís commercial success. These terracotta cast stones were used for interior and exterior ornamental elements. Coade Stone is acid resistant and weathers well. It was used for statues, tombs, balustrades, vases, pillars and decorative architectural elements.
Rangerís artificial stone was patented in 1832 and named after its inventor. This artificial building stone combined a hydraulic lime with an aggregate such as beach shingle or broken flints and boiling water, which apparently produced a rapid set.
Silicious Concrete Stone was an artificial stone made with water glass. It was made by a process patented by F. Ransome in 1856. In this process, water glass (sodium silicate) is mixed with sand (and gravel, flint, chalk, or limestone) in an aqueous solution of caustic soda. Then this alkaline solution is mixed with calcium chloride to form an insoluble silicate stone.

- Conclusion

This historical overview of materials used in plaster and artificial stone, prior to and in the 19th and 20th centuries is by no means meant to be exhaustive. However, it should shed light on the variety of materials and mixes used over the centuries, and in particular in the last two centuries. Their use has occasionally given rise to problems of permanence, and we are now faced with the challenge of their conservation. It is only by knowing accurately the composition of these materials that the survival of remaining examples can be assured.

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