PLASTER AND PLASTER BOARD PRODUCTION

Gypsum plaster has been used as building material for at least 4000 years. Currently it is used to make plaster boards, fibrous plaster, building decorations and moulds for many applications. Plaster is produced in New Zealand by Winstone Wallboards Ltd. using the following process:

Step 1 - Plaster of Paris Manufacture
The gypsum ($CaSO_4.2H_2O$) is heated to remove 75% of its combined water, resulting in the formation of Plaster of Paris ($CaSO_4.\frac{1}{2}H_2O$). This reaction is called calcination.

$$CaSO_4.2H_2O \rightarrow CaSO_4.\tfrac{1}{2}H_2O + 1\tfrac{1}{2}H_2O$$

Step 2 - Rehydration
Dry plaster powder is mixed with excess water and any additives. It can then be cast in moulds, extruded, applied as a thick slurry to a surface or laminated between paper boards.. The additives are used to change the density of the plaster and, in the case of plaster board, to help the plaster to mechanically bond to the cardboard. The basic rehydration reaction is the reverse of calcination:

$$CaSO_4.\tfrac{1}{2}H_2O + 1\tfrac{1}{2}H_2O \rightarrow CaSO_4.2H_2O$$

Step 3 - Setting
In a manufacturing operation, excess water is added to ensure complete rehydration of plaster back to gypsum and to provide sufficient fluidity for manufacturing processes. The excess water is then removed either by simply leaving the plaster to dry by evaporation or by heating it to up to 250^{o}C for up to 60 minutes. During this time the plaster solidifies so that it can be removed from a mould in one piece.

INTRODUCTION

Plaster is one of the oldest known synthetic building materials: it was used by the Egyptians at least 4000 years ago in the construction of the pyramids, and the Greeks were producing decorative plaster work by 500 BC. The chemistry of the conversion of gypsum to plaster was also investigated early on by chemists such as Le Chatelier (1850 - 1936) and van't Hoff (1852 - 1911).

Plaster is made by heating gypsum ($CaSO_4.2H_2O$) powder, thus converting it to calcium sulphate hemihydrate ($CaSO_4.\frac{1}{2}H_2O$). The hemihydrate is also known as stucco or Plaster of Paris — probably so named because of the very large deposit of pure gypsum found beneath Paris. When water is added to the stucco, the material rehydrates to give a solid mass of gypsum. This rehydration is accompanied by an increase in temperature and a slight expansion of the plaster, causing the gypsum to perfectly fill a mould.

Uses of plaster
Present uses of plaster include the manufacture of:

- *plaster boards* - a layer of plaster sandwiched between two sheets of cardboard. Probably the best known example is Gib® board
- *fibrous plaster* - plaster with fibres (often made of glass) mixed into it to increase its strength. Fibrous plaster is usually cast into a mould then used in slabs.)

- *plaster cornices* - the decorative plaster projections used under the eaves and above doorways and windows in buildings
- *plaster mouldings*
- *chalk plaster*

Plaster is also used for solid plastering in building and to make moulds for casting pottery and crockery, for making false teeth and for casting metal to make boat keels.

Most of the plaster produced is used in the production of Gib® board and fibrous plaster, with about 80% being used for Gib® alone. This is because plaster is of great importance to the building industry as a fire retardant. When gypsum plaster is exposed to fire, every kilogram of plaster will slowly release 200 g of water in the form of steam as follows:

$$CaSO_4.2H_2O \rightarrow CaSO_4.\tfrac{1}{2}H_2O + 1\tfrac{1}{2}H_2O$$

This water acts as a heat barrier, ensuring that the temperature behind the plaster board does not rise appreciably above the boiling point of water and thus preventing the fire from crossing over the board.

THE MANUFACTURING PROCESS

Winstone Wallboards Ltd. in Auckland and Christchurch is the sole plaster manufacturer in New Zealand, and each year they produce between 110 000 and 150 000 tonnes of plaster. This is either sold as a base material for specialised plaster products or used on site in the production of plaster board.

Step 1 - Plaster of Paris Manufacture

Gypsum is imported from South Australia in large shipments of up to 25 000 tonnes at a time. Immediately before it is used, it is ground and dried in a heated mill to give a fine powder. The ground gypsum is then charged into large steel kettles of ten tonnes capacity, which are heated by gas burners and stirred internally by rotating paddles to prevent localised overheating. As the contents of the kettle heat up, the escaping steam from the water of crystallisation being driven off causes the gypsum to "boil" and calcination to occur:

$$CaSO_4.2H_2O \rightarrow CaSO_4.\tfrac{1}{2}H_2O + 1\tfrac{1}{2}\,H_2O$$

During this reaction the temperature must be carefully controlled. Above the optimum temperature range unwanted side reactions involving excessive water loss occur:

$$CaSO_4.\tfrac{1}{2}H_2O \rightarrow \underset{\text{soluble anhydride}}{CaSO_4\ (\text{trace } H_2O)} + \tfrac{1}{2}H_2 + \tfrac{1}{2}O_2 \quad \text{at } 175°C$$

$$CaSO_4.\tfrac{1}{2}H_2O \rightarrow \underset{\text{insoluble anhydride}}{CaSO_4} + \tfrac{1}{2}H_2O \qquad \text{at } 425°C$$

Where there is inadequate stirring, hot spots can form in which quicklime is produced:

$$CaSO_4 \rightarrow \underset{\text{quicklime}}{CaO} + SO_3 \qquad \text{extreme heat}$$

With careful temperature control, the levels of both unwanted anhydrides can be kept well below their respective permissable maximums of 5% and 2% and quicklime can be completely eliminated.

When the required temperature is reached, the plaster is dropped into pits to cool it rapidly to prevent any further calcination. It is then ground and stored in large silos for further use.

Step 2 - Rehydration
Some of the plaster is sold as Plaster of Paris powder, but the majority is moulded on site. This involves rehydrating it to gypsum in accordance with the following reaction:

$$\underset{\text{Plaster of Paris}}{CaSO_4.\tfrac{1}{2}H_2O} + 1\tfrac{1}{2}H_2O \rightarrow \underset{\text{gypsum}}{CaSO_4.2H_2O}$$

This chemical reaction requires 18.3 parts of water per 100 parts of plaster by weight. However, in practice 60 - 80 parts of water are used so that the plaster can easily be poured into a mould before it sets.

Along with the water, various additives may be used to change the way in which the plaster sets. Some of these additives are listed in **Table 1**.

Table 1 - Common plaster additives

Additive	Function
starch	Used in plaster board to protect the physical bond between the gypsum crystals and the cardboard during drying.
ground gypsum	Provides many sites at which gypsum crystals can grow, thus accelerating the setting rate.
lignosulphonates	Improves the flow of the slurry so less water is required, resulting in a denser plaster.
potassium sulphate	Causes the gypsum to precipitate out quicker due to a common ion effect.
detergent	Forms a foam in the mix, resulting in a less dense plaster. The detergent chosen must form a foam in hard water (i.e. water containing a high concentration of calcium ions).

Plaster board production
For most of the plaster produced by Winstone Wallboards the 'mould' is two sheets of cardboard between which the plaster is continually extruded to form Gib® plaster board. Plaster board is produced in such large quantities because its sheet form and transportability make it much more convenient to use than plaster itself, which is a very brittle substance.

Step 3 - Setting
As the plaster sets, the residual water is removed by heating in a drying oven for up to 60 minutes at temperatures of up to 250°C, or by exposure to the wind in covered outdoor racks. By the time drying is complete, all but 0.5% of the excess water has been removed. The water leaves pores in the cast that account for more than 50% of the volume of an average plaster, although this density can be altered by the use of certain additives (see **Table 1**). The detailed chemistry of the setting process is complex, but it appears the hemihydrate ($CaSO_4.\tfrac{1}{2}H_2O$) dissolves in the water and the less soluble dihydrate ($CaSO_4.2H_2O$) is precipitated out:

$$\underset{\text{powder}}{CaSO_4.\tfrac{1}{2}H_2O} + 1\tfrac{1}{2}H_2O \rightarrow \underset{\text{interlocking crystalline mass}}{CaSO_4.2H_2O}$$

The setting reaction is characterised by an induction period during which very little happens, and it is during this time that additives are mixed in and the mould is filled. This is followed by the setting reaction which leaves the plaster as a solid mass which can be removed from the mould.

ROLE OF THE LABORATORY

The laboratory is involved in quality control analysis at all stages of production. Some of the tests carried out are as follows:

- measurement of the sizes of both the gypsum and Plaster of Paris particles after grinding using a vacuum separator
- measurement of waters of crystallisation using a highly accurate balance
- board strength
- board weight
- fire resistance

ENVIRONMENTAL IMPLICATIONS

The production of plaster and plaster board puts very little pressure on the environment. The final product is non-toxic and wastage and unwanted by-products from the process are minimal.

The only current issues of concern are dust and CO_2 emissions. The dust emissions are kept to an extremely low level by the use of dust collectors throughout the plant, but CO_2 emissions are much more difficult to control. CO_2 production during gas combustion is difficult to avoid, but the Winstone Wallboards is endeavouring to keep CO_2 emissions at 1990 levels.

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