DEPARTMENT OF COMMERCE

BUREAU OF STANDARDS
George K. Burgess, Director

CIRCULAR OF THE BUREAU OF STANDARDS, No. 151

WALL PLASTER: ITS INGREDIENTS, PREPARATION, AND PROPERTIES

January 9, 1924

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WALL PLASTER: ITS INGREDIENTS, PREPARATION, AND PROPERTIES.

(Report of the Bureau of Standards Plastering Conference.)

ABSTRACT.

The art of plastering is intimately connected with the comfort and safety of the occupancy of buildings. Yet few outside the trade understand the nature of the material and the details of the work required to produce the desired results. The recently aroused interest in building has carried with it interest in plastering.

Much information about the factors which enter into successful plastering was found available in the trade. This paper represents an attempt to collect and correlate this information for the public benefit.

To assist in the work a committee known as the Bureau of Standards Plastering Conference was organized of men most familiar with the different phases of the subject. From the information thus furnished, and from laboratory research work, we have been able in many cases to explain not only how an operation is conducted, but also why this is the best way of doing it.

It is recommended that furring be used when plastering exterior masonry walls, to prevent damage due to condensed moisture.

When masonry walls are to be plastered without furring, the surface of the masonry should be true and clean and of the proper degree of wetness.

Specifications and directions for erecting are given for wood, wire, and metal lath, and gypsum plaster board.

Descriptions and specifications are given for the ingredients of plaster—lime, gypsum, cement, sand, hair, water, etc.

The chief properties of the wet mix are discussed, as they affect the quality of the finished plaster.

Complete directions are given for the mixing of the ingredients and the application of the wet mix to the wall.

The chief properties of the hardened plaster are discussed as they affect the comfort and safety of the occupant.

Different kinds of decorative features are described.

Some of the common defects are described, and their causes and remedies suggested.

Attention is called to the factors to be considered when selecting materials for plastering, in order that they may be best adapted to the particular case.

CONTENTS.

I. INTRODUCTION.

1. REASON FOR THE WORK.

The occupant of a building is intimately and continuously cognizant of the quality of the plaster on the walls and ceilings. Daily impression, made perhaps unconsciously upon his mind, compels him to become aware of whatever faults or excellencies it may possess. To him, its obvious value is decorative. It has other functions which are frequently lost sight of, though they are none the less important. Its ability to resist fire may provide sufficient time to give the fire apparatus opportunity to arrive before the fire has gained too much headway. Its ability to absorb sound is of obvious value in theaters, churches, and apartments. Its resistance to the passage of heat has a measurable effect on the quantity of fuel required to maintain comfort.

If plaster is regarded as only a decorative medium, it should not properly be subjected to police regulation. This view is taken by most cities, which ignore, or only inadequately provide for, plaster in their building codes. On the other hand, if the other properties of plaster are of sufficient importance to affect the utility and safety as well as the pleasure of occupancy of a building, city councils should take cognizance of the fact. There is a distinct modern tendency to substitute "blue-sky laws" for the old rule of caveat emptor.

If cities do decide to legislate about the quality of plaster, they will need a comprehensive statement as to present practice as a basis for action. If they do not, it is all the more necessary that the private citizen shall have such a statement for his own guidance in the selection of materials and the supervision of work.

Because of conditions peculiar to certain localities, practices based largely upon custom have grown up. Changes in practice have not always followed changes in conditions. A wider knowledge of these local peculiarities, by enabling one to select the good and discard the bad in all, would tend to raise the standard of the entire industry, and promote the safety, comfort, and health of the occupants of buildings.

2. BUREAU OF STANDARDS PLASTERING CONFERENCE.

For the reasons cited above, the bureau felt impelled to collect the existing information, and, by research, to develop data where necessary, in order that this knowledge may be made available to those interested. In this work, the bureau has been particularly fortunate in securing the active cooperation of national associations dealing with all phases of the industry. The representatives of these associations comprise the Bureau of Standards Plastering Conference, and the bureau wishes here to express its deep appreciation of the willingness with which they have placed their knowledge at its disposal.

While every statement in this report has not received the unanimous approval of the conference, all statements are backed by a very substantial majority.

The personnel of the conference as of January 1, 1923, is as follows:

MATERIALS MANUFACTURERS.

Portland Cement Association, W. E. Hart, Chicago, Ill.
Common Brick Manufacturers Association, W. Griffiss, Baltimore, Md.
Hollow Building Tile Association, F. J. Huse, Chicago, Ill.
The Gypsum Industries:
  D. L. Haigh, New York, N. Y.
  V. G. Marani, Chicago, Ill.

Associated Metal Lath Manufacturers, W. Clay, Chicago, Ill.
National Lumber Manufacturers Association, R. G. Kimbell, Washington, D. C.
National Lime Association:
R. P. Brown, Washington, D. C.
T. B. Shertzer, New York, N. Y.
National Association of Sand and Gravel Producers, T. R. Barrows, Washington, D. C.
Associated Tile Manufacturers, M. A. Illing, Beaver Falls, Pa.
New Jersey Wire Cloth Co., L. G. Beers, Trenton, N. J.

USERS.

Contracting Plasterers International Association, J. J. Earley, Washington, D. C.
Operative Plasterers and Cement Finishers International Association, J. F. O'Reilly, Jersey City, N. J.
Wood, Wire, and Metal Lathers International Union, W. J. McSorley, Cleveland, Ohio.

INDEPENDENT.

National Board of Fire Underwriters, I. H. Woolson, New York, N. Y.
Supervising Architect, U. S. Treasury Department, J. S. Ginder, Washington, D. C.
American Institute of Architects, L. R. Kern, New York, N. Y.
Structural Service Bureau, D. K. Boyd, Philadelphia, Pa.

BUREAU OF STANDARDS.

Cement: J. C. Pearson.
Lime and Gypsum: W. E. Emley, Chairman.
Fire Resistance:
S. H. Ingberg.
N. D. Mitchell.
Acoustics: E. A. Eckhardt.

3. DEFINITION OF PLASTER.

When dry material is mixed with water into a plastic mass, which subsequently hardens to form the surface of an interior wall or ceiling, the term plaster is applied to the material in any of its three stages—dry powder, plastic mass, or hardened surface.

It is specifically to be noted that this definition makes no reference to the kind of material, but that it does confine the location of its use to interior surfaces only.

It is realized that the above definition includes certain types of paint, but it is believed that this will not lead to any important confusion.

4. GENERAL NOTES ON BUILDING CONSTRUCTION.

Everyone is familiar with the way structural steel expands as the temperature rises, and with the way wood expands when it gets wet. Few people stop to consider that brick, concrete, and, in fact, all building materials are subject to similar volume changes under the influence of these two factors—temperature and humidity. Not only is the framework of a building continually changing in size and shape, but the bearing power of the soil on which the building is erected is subject to the same influences.

Fortunately the magnitude of these movements is usually so small as to be well within the elastic limit of the plaster; otherwise, plaster without cracks would be practically unknown. Larger movements may produce no serious effects if they take place with sufficient slowness. The plaster seems to undergo a sort of "plastic flow," which, if given time, will relieve stresses caused by very considerable movements of the building.

One must expect the structural members of a building to move continuously throughout their lives. These movements can not be eliminated, but a proper design of the structure will hold them within safe limits under ordinary conditions. If sufficient rigidity is provided for safety and durability, provision for further rigidity to prevent cracking of the plaster is a question of economy, repairing cracked plaster being considered as an item of maintenance cost.

5. KINDS OF PLASTERING.

The word "plastering" (used as a noun) is given a broader definition than the word "plaster." Plaster is usually confined to the material. Plastering includes the plaster, the backing to which it is applied, the workmanship used in the application, and the subsequent history of the completed structure.

Plastering may be divided into two kinds, depending upon whether the plaster is applied to a masonry backing or to a lath backing. These will be taken up in detail in Sections III and IV, respectively. In most cases, the choice between masonry and lath is dictated by circumstances beyond the control of the plasterer. The use of furring, where the wall is designed solely for the purpose of receiving plaster, permits the plasterer to choose the materials, so it will perhaps be better to discuss this case first.

II. FURRING.

1. DEFINITION.

"Furring" is the trade term applied to a type of construction wherein there is provided an air space between the solid surface of a wall or ceiling and the plaster.

2. CONSTRUCTION OF FURRING.

The furring of a wall may be accomplished by the use of one of three quite different types of material—furring tile, furring strips and lath, or self-furring lath.

Furring tiles are now made of either clay or gypsum. In appearance they resemble a hollow building tile which has been split longitudinally along the axis of the core or cell. They are set in place to form a sort of false wall with the core spaces next to the masonry, the plane face of the tile being exposed to receive the plaster. The core spaces in the tiles thus provide the desired air gap between the plaster and the wall.

Furring strips may be of wood or metal. They are narrow, wooden strips or steel shapes fastened to the masonry at regular intervals. Lath is attached to these strips, and plaster is applied to the lath. In this way the plaster is prevented from coming into contact with the masonry, leaving an air space in the wall.

Self-furring lath is a type of metal lath in which metal stiffeners are built into the sheets of lath. When the lath is erected with these stiffeners next to the masonry they become, in effect, furring strips.

It is preferable, whether tile or strips be used, to have the air spaces continuous in a horizontal rather than a vertical direction. This will prevent the vertical circulation of the air in the space, and thereby reduce the transfer of heat by convection.

3. REASON FOR USE OF FURRING.

It was noted above that a masonry wall is continuously undergoing expansion and contraction. If these movements are not extraordinarily large, and if the bond between the plaster and the masonry is good, no cracks in the plaster should result. Furring may be considered as an additional insurance against cracks from this cause. Since the false wall to which the plaster is applied is protected from exposure to those weather conditions which affect the masonry wall, the movements in it take place more slowly and are of less magnitude.

Imperfect drainage may cause water to seep through a foundation wall; a long-continued beating rain may produce the same effect on walls above grade. If plaster is applied directly to the wall, this water will readily come through the plaster, to the detriment of the paper or paint on its surface. Furring interposes an air space in the path of the water, and impedes its progress.

It is well known that for moderate temperature differences a small, confined air space has a much greater ability to resist the passage of heat than has a solid wall of equal thickness. It is probably true that unless special precautions are taken, most of the heat lost from our buildings passes out through the windows and doors, so that no marked economy could be expected from increasing the thermal resistance of the walls.

This thermal resistance is much more important as an aid in the prevention of condensation. If the air on the outside of a wall is much colder than that on the inside, and the wall is solid, it will tend to assume a temperature midway between the two. It may thus easily happen that the wall will be cooled below the dew point of the air in the building, and moisture will condense on its surface. If the wall is furred, the masonry will approach more closely the temperature of the outside air, but the plaster will approach more closely that of the inside air, and there is thus much less danger of having the plaster cooled below the dew point.

The heat capacity of a masonry wall is quite large. If it is thoroughly cooled during the night, considerable time is required in the morning to heat it to the temperature of the surrounding air. This lag may be great enough to keep the wall below the dew point of the air for several hours. If the wall is furred, then it is not the heavy wall but only a thin sheet of plaster which must be heated.

The unexpected appearance of water on the surface of plaster may result merely in the temporary wrinkling of the wall paper, or it may seriously impair the value of priceless mural decorations. The appearance of this water can usually be ascribed to condensation on the surface rather than transmission through the wall, but furring has proved effective in lessening the danger in either case.

4. WATERPROOF PAINTS.

Some attempts have been made to use a waterproof paint to accomplish the same results as furring. The paint must necessarily close the pores in the masonry (see Section III, 3), and if it is waterproof it will be impossible to get a bond between it and the plaster. Unless the surface of the wall is such as to provide a good mechanical bond for the plaster, the usual type of waterproof paint should not be used.

In the newer type of paint, particularly designed for this purpose, small particles of stone are firmly embedded in the paint. The plaster can be bonded to these stones, so that this difficulty is overcome. Such a paint coat would obviously prevent the transmission of water through the wall. Furring increases the thermal resistance of the wall to an extent far greater than could be expected of a coat of paint. In fact, except in so far as it prevents actual flow of air through the wall, the added resistance of the paint is so slight as to be negligible.

5. RECOMMENDATIONS AS TO USE OF FURRING.

There are certain localities in the United States where the climate is uniformly hot and dry. (In the preceding sentence particular emphasis is to be placed on the word "and.") With the exception of such localities, it is recommended that all exterior masonry walls be furred. The improved durability of the plaster and decorations, and the comfort of occupancy, amply justify such a recommendation.

6. SPECIFICATIONS FOR FURRING MATERIALS.

The only important requirement about a furring tile is its thickness. It is specified that this dimension shall be not less than 1½ inches. It is also necessary that the surface of the tile shall be adapted to receive plaster, and that the tile shall be strong enough to make a satisfactory wall. These points are hardly of sufficient importance to specify. Furring tile are usually 12 by 30 or 12 by 12 inches. The thickness of furring strips shall be such that, when erected, the distance from the back of the lath to the inside face of the masonry shall be not less than one-half nor more than 1 inch.

7. ERECTION OF FURRING TILE.

The tile shall be bonded firmly to the structural members at top and bottom by bedding and wedging them in mortar, but there shall be no mortar bond between the tile and the masonry wall. The tile shall be bonded to the masonry by means of metal wall ties firmly embedded in the masonry, spaced not more than 2 feet on centers vertically or 3 feet horizontally. All vertical joints shall be broken every course. The tile shall be laid to produce a plumb and true surface for plastering. The surface shall be prepared to receive plaster, in conformity with the suggestions given in Section III.

The mortar to be used with clay tile shall be of the following composition: 1 bag of Portland cement, 1 bag of hydrated lime, and 6 cubic feet of sand. For gypsum tile, use 1 bag of neat gypsum plaster to 2 cubic feet of sand.

8. ERECTION OF FURRING STRIPS.

Furring strips shall be firmly secured to the masonry by means of metal plugs, metal wall ties, or nails, spaced not more than 3 feet apart, along the length of the strip. The strips themselves shall be spaced not more than 16 inches on centers. When a furring strip is parallel to a corner angle, or edge of an opening, it shall not be closer than 1 inch thereto.

Lath shall be attached to these furring strips in accordance with the directions given in Section IV.

9. ERECTION OF SELF-FURRING LATH.

The furring strips or stiffeners, which form a part of the lath, shall be attached to the masonry as though they were separate strips. (See Section II, 8.)

The lath shall be erected in such a way as to conform to the requirements given for the appropriate type of metal or wire lath in Section IV.

10. SUSPENDED CEILINGS.

It is sometimes desirable to make use of the principle of furring in the construction of ceilings. If the ceiling is the under side of the roof, or where excessive condensation may be expected, the insulating value of furring may be brought into play. If the floor is constructed in such a way that the beams project below it, and it is desired that the ceiling shall be plane, the plaster must be suspended from the masonry.

To construct a suspended ceiling, metal stirrups of appropriate lengths shall be rigidly fastened to the floor, spaced 4 feet apart each way. Runner bars, spaced 4 feet on centers, shall be rigidly fastened to these stirrups. Furring strips, consisting of steel shapes or pencil rods of sufficient strength, shall be rigidly fastened to the runner bars in such a way that they all lie in the same plane, are parallel to each other, and 1 foot apart.

The lath shall be attached to these strips in such a way as to conform to the requirements given for the appropriate type of lath, in Section IV.

III. PREPARATION OF A MASONRY WALL TO RECEIVE PLASTER.

If it is desired to apply plaster directly to a masonry wall, the wall must have certain characteristics. These can be developed during the construction of the wall or by subsequent treatment. It is always necessary that the wall shall be true and clean, and it is sometimes equally necessary that it shall be rough or wet.

1. TRUENESS.

The masonry wall to which plaster is to be applied should be reasonably true, with all angles and corners sharp and straight. It is required that the exposed surface of the plaster shall be plane. If the plaster is much thicker in some places than in others, unequal expansion and cracking are likely to result. The masonry must therefore be as nearly plane as its roughness will permit.

2. CLEANLINESS.

Any foreign material on the surface of masonry will interpose between the masonry and the plaster and thereby prevent the formation of the desired bond. Brick or tile walls are apt to have pieces of mortar weakly adhering to them; a concrete wall may be coated with laitance, or it may have picked up grease spots from the forms. All such extraneous matter must be removed before the wall is plastered.

Laitance will be removed satisfactorily if a hatchet is used to roughen the wall. Grease spots can be burned out with a blow torch. A wire brush is useful in the removal of other kinds of dirt.

3. ROUGHNESS AND WETNESS.

The way in which a wall receives plaster is a good indication as to whether or not it is suitably wet or rough. If the plaster can not be spread, but adheres to the wall in lumps, the wall is too dry and must be wetted. If the plaster tends to stick to the trowel rather than to the wall, or if it tends to slide or fall off, the wall may be too wet, in which case the plastering must be postponed until some of the water has evaporated. If it is known that this is not the case, then the wall must be too smooth, and must be roughened by some suitable means, resorting to furring if necessary. The degree of roughness necessary is thus seen to be a function of the absorptive ability of the wall—the more absorptive a wall, the smoother it may be.

It should be emphasized that the way in which a wall receives plaster must be regarded only as a method of test. True, it is of some importance that the plaster can be applied with facility, but the condition of the wall which this indicates is of far greater importance as affecting the quality of the plastering. An absorptive wall is porous. When the surface pores are filled with plaster, they act as mechanical keys to bond the plaster to the wall. In proportion as the pores are diminished in number, the roughness of the surface must be increased. Chopping a concrete wall with a hatchet may, therefore, be considered as a clumsy attempt to increase its porosity. If the wall is too wet, the surface pores are filled with water, and the plaster can not be pushed into them. Some water is necessary to take part in the chemical reactions involved in the hardening of the plaster, and if the wall is so dry as to suck this water out immediately, the hardening may be impeded or even prevented.

A concrete wall, poured in unplaned forms and plastered while still green, will probably need no further preparation for plastering other than the removal of laitance and grease. If the forms were planed the concrete may have to be roughened by chopping it with a hatchet. If the concrete has been allowed to dry out, it will probably have to be wetted again.

A vitrified brick is so smooth and nonabsorptive that it can not be plastered without the aid of furring. Other kinds of brick walls (provided they have not been painted) can usually be plastered without further preparation. They are too smooth to provide much mechanical bond, but the absorption is about right, so that roughness is not required. The mortar joints must be cut back to the face of the brick to make the surface plane as noted in Section III, 1.

Tile are scored during the process of manufacture. The absorption of glazed clay tile is so low that this scoring is essential to provide the necessary roughness. Unglazed clay tile and cement tile have about the same absorption as brick. The scoring assists in the application of the plaster, and, perhaps, gives some further assurance of a good bond, but it is not essential. The absorption of gypsum tile is comparatively high, and the scoring is of correspondingly little importance. It is useless to wet glazed tile before plastering, and gypsum tile should not be wetted. Other kinds of tile may be wetted, but this will seldom be found necessary. Mortar joints must be cut back at least even with the face of the tile. A projecting mortar joint would create a thin, and therefore, weak section in the plaster.

IV. LATH.

1. THE FUNCTIONS OF LATH.

Lath is a material which is designed to act as a base to which plaster is applied. It is fastened to the studs or to the masonry either directly or by means of furring strips, and is so made that the plaster will firmly adhere to it.

Probably the most important function of lath is to hold the scratch coat of plaster in position until it has had time to harden. It must next display sufficient rigidity to prevent the "key," or mechanical bond, of the scratch coat from breaking when the brown coat is applied. Finally, it acts as a reinforcing material to distribute any strains which may come upon the hardened plaster, thus reducing the tendency to crack.

2. KINDS OF LATH.

There are three kinds of lath in general use—wooden, metallic, and gypsum plaster board.

Metallic laths may be further subdivided into three classes—sheet, expanded metal, and woven wire. Sheet-metal lath is perforated in order that the plaster may be pushed through the holes to form a bond. Expanded metal lath is made by cutting slots in sheets of metal and then stretching the sheets, thus making the slots take on a diamond or some other shape. This type seems to have obtained exclusive use of the term "metal lath." Chicken wire is a familiar example of woven wire. This can be used as a lath, but it is preferable to use a heavier wire and a smaller mesh.

Gypsum plaster board is a sheet of gypsum plaster inclosed between two sheets of paper. It can be nailed or clipped to the studs, and the paper on its surface is not sized, so that plaster will adhere to it.

3. CONSIDERATIONS GOVERNING THE SELECTION OF LATH.

A wood lath, especially if it has a crooked grain, may warp or buckle when it gets wet. If the lath are thoroughly soaked prior to erection, the few bad ones in the shipment can readily be culled out. At any rate, the warping can be detected and repaired before the plastering is completed.

The incombustible nature of metal lath or gypsum plaster board is of decided importance even if they are attached to wooden furring strips or studs. Plaster is effective as a fire resistive material only so long as it is able to stay in place and prevent the fire from going through it into combustible structural members. It is true that many fires start in the basement and travel upward inside the partitions, thereby attacking the plaster in the rear. In such cases metal lath or gypsum plaster board might be recommended, but it is believed better practice to introduce fire stops to prevent fire from spreading in this way.

Where metal lath covered with gypsum plaster is exposed to dampness, and particularly where there is a possibility of stray electric currents grounding in the lath, there is some danger of corrosion. This can be overcome by the use of painted, or, under more severe conditions, galvanized lath, and lime or cement plaster.

The heavier the metal lath the greater its value as a reinforcement for the plaster. For this reason lighter lath may be used on walls than on ceilings or in dwellings than in public buildings. For exceptionally heavy duty, as when the supports are more than 16 inches apart, sheet, ribbed, or reinforced metal lath should be used.

The nature of wire lath is such as to permit the lath to become completely embedded in the plaster. Complete protection may thus be afforded against possible deleterious effects which might result from exposure of the lath, and there is definite assurance of a good bond between the lath and the plaster.

4. SPECIFICATIONS FOR WOOD LATH.

The value of a wood lath depends upon the kind of wood of which it is made and its dimensions.

The grading of lumber is a problem which is peculiarly local. Spruce is graded upon entirely different characteristics than oak; the basis of grading depends upon the wood involved, and this depends upon the locality. Consequently a No. 1 lath in Oregon is a quite different material from a No. 1 lath in Georgia. It seems impossible, therefore, to write specifications which will be generally applicable. Since official grading bureaus have been established in different localities, it would seem advisable, under the circumstances, to accept the rulings of these bureaus and simply specify that either No. 1 or No. 2 lath may be used. The purchase of No. 2 lath will probably result in the necessity of culling out a greater number of unsatisfactory laths from a shipment either because they warp out of shape when wet or because they contain live knots, the resin from which may come through the plaster and discolor it.

A peculiarity of wood is the comparatively large expansion across the grain when it gets wet. If the lath are not completely saturated when the plaster is applied, they will absorb water from the plaster and expand. If the plaster hardens before this expansion is complete, it may shear the key, breaking the bond between the lath and the plaster. If the plaster does not harden until afterwards, the subsequent drying and contraction of the lath will leave it loose in the plaster. The best way to reduce the amount of this expansion is to reduce the dimensions across the grain of the wood. It is, therefore, specified that wood lath shall be one-fourth inch thick by 1½ inches wide, with permissible variations of one-sixteenth inch in thickness and one-eighth inch in width, plus or minus.

Commercial lengths of wood lath are 32 or 48 inches, with a permissible variation of one-fourth inch, minus only.

5. ERECTION OF WOOD LATH.

Supporting furring, joists, or other ground for the attachment of wood lath shall be spaced not more than 16 inches center to center. The face of a single supporting member shall not exceed 4 inches in width. Where wider support is used, it shall be offset from the face of the wall sufficient to allow the application of a narrow furring strip. Supporting members shall be arranged in true alignment and be made rigid to provide secure and permanent hold for nails. Such members shall be solid at angles and corners to prevent the extension of lath through the angles.

Lath on walls shall be laid horizontally. In narrow panels they shall not be placed at an angle to exceed 60° from the horizontal. Lath on ceiling shall run in one direction only. Joints shall be broken at least every seven laths.

Laths shall be spaced not less than three-eighths inch apart. There shall be a space of one-fourth inch between abutting ends of laths.

All lath shall be nailed to each stud, joist, furring, or other bearing which it crosses.

Unless the lath are quite green, they shall be thoroughly wetted as late as practicable prior to the application of the plaster.

6. SPECIFICATIONS FOR SHEET AND EXPANDED METAL LATH.

There are many styles of these kinds of lath on the market, having openings of different sizes and shapes. Those having larger openings must be made of thicker metal to have the same rigidity. It is therefore believed that a requirement as to weight is about the only one necessary. These materials are made in many different weights, even the lightest being satisfactory for some purposes. The specification, therefore, takes the form of recommended minimum weights of lath to be used for given purposes, as follows:

	Pounds per square yard.		
	Light.	Medium.	Heavy.
Expanded lath, no ribs	2.2 to 2.5	3.0	3.4
Expanded lath, ribbed	2.5	3.0	3.8 or 4.8
Sheet lath	None.	None.	4.5

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The kinds of plastering which require the use of heavy, medium, or light lath, are described in Section XI.

All sheet and expanded metal lath shall be painted or galvanized.

7. SPECIFICATIONS FOR WIRE LATH.

The following specifications for wire lath are based upon what has been found by experience to meet the requirements of the trade:

Wire lath shall be woven of No. 19 or No. 20 wire.

It shall have two or two and one-half meshes per linear inch.

It shall be galvanized after weaving.

8. ERECTION OF METALLIC LATH—ALL KINDS.

Where supports are more than 16 inches on centers for walls, or 12 inches on centers for ceilings, an extra heavy style of sheet or ribbed lath shall be used.

The face of a single supporting member to which lath is to be directly attached shall not exceed 4 inches in width. Where wider support is used it shall be set back from the face of the plaster sufficiently to allow the application of a narrow furring strip. Supporting members shall be arranged in true alignment and be made rigid to provide secure and permanent base for attaching the lath.

The sheets of lath shall be laid with the longer dimension across the supports. Except in narrow panels, the end of a sheet shall be placed at least one support distant from any angle. and the sheet bent around or into the corner.

Each sheet shall be securely fastened to every support it crosses. The points of attachment between the lath and the support shall be not more than 6 inches apart, along the length of the support.

When fastening adjacent sheets of metal lath together, the main object to be considered is that the entire surface of the room shall be covered with a continuous fabric, which must be, as nearly as practicable, of equal strength and thickness throughout. If the sheets of lath are butted together, the requirement for equal thickness can be met, but it is practically impossible to make the butted joint as strong as the sheet. A better method is to lap the sheets exactly one full mesh. The holes in the lath will then come over each other, and the plaster can be pushed through both to hold the sheets together as by a dowel. It is true that this results in increased thickness along the joints, but if the sheets are lapped not more than one mesh, the area is comparatively small and unimportant. The joints between the ends of sheets shall, wherever possible, come over supports. Where this is not possible, they shall be tied once every 6 inches. The joints between the sides of sheets shall be tied once midway between each support.

9. SPECIFICATIONS FOR GYPSUM PLASTER BOARD.

Gypsum plaster board shall conform to the requirements given in the current specification issued by the American Society for Testing Materials No. C37.

10. ERECTION OF GYPSUM PLASTER BOARD.

Supports for gypsum plaster board, when of wood, shall be spaced not more than 16 inches on center; metal supports shall be spaced not more than 30 inches on center. They shall be arranged in true alignment and be made rigid to provide secure and permanent base for attaching the board.

Each board shall be securely fastened to every support it crosses. If the support is of wood, the board shall be fastened to it with nails spaced not more than 6 inches apart, along the length of the support. If the support is of metal, the edges of the board parallel to the support shall be attached to it at intervals of 9 inches, and the other edges shall be attached to each support they cross.

Two opposite edges of each board must come over a support. There shall be a clearance of one-fourth inch between adjacent boards, on all edges. Joints at right angles to the supports shall be broken every board. If gypsum plaster board is used on both sides of a partition, the joints between the boards shall not come opposite each other.

Gypsum plaster boards shall not be wetted prior to the application of the plaster.

11. SOLID PARTITIONS.

The commoner type of nonbearing partition consists of a masonry wall plastered on both sides, or a stud wall with lath and plaster on both sides. A newer type consists of a row of studs with lath and plaster on one side, the same lath being back plastered to produce the opposite surface.

Probably the most important argument in favor of this type of partition is its economy of space and material. Solid partitions are usually 2 inches thick, whereas it is difficult to build a satisfactory partition of the usual type much less than 6 inches thick. On the other hand, its acoustical properties and heat conductivity are such as to limit its use.

Supports for solid partitions shall be three-fourths inch steel channels or their equivalent. They may be erected by springing them into holes in the floor and ceiling, or they may be attached to floor and ceiling by means of metal shoes. They shall be erected in true alignment, spaced 16 inches on centers for metal lath, or from 24 to 30 inches on centers for gypsum plaster board. Metal lath or gypsum plaster board shall be attached to them as specified in Sections IV, 8 or IV, 10.

If the partition is more than 14 feet high, proportionately heavier channels shall be used.

12. CORNER BEADS AND CORNERITES.

An angle, whether it be reentrant or projecting, is normally the weakest section of plaster. If the abutting walls, or wall and ceiling, are constructed of different materials, and the normal forces causing expansion and contraction are brought into play there is very apt to be a differential motion which will open the joint between the walls. This is particularly likely to happen where one of the walls is external and thus subjected to all the variations of the weather.

A straight line crack, confined strictly to the corner, is not particularly unsightly; in fact, it is not often noticeable. If it occurs between a partition wall and a ceiling, it may afford a little shorter path for fire to travel to the story above.

A corner bead is a strip of metal bent longitudinally to form an angle, to fit around an external corner. The sides of the angle extend a few inches back on each wall and are perforated to provide keys for the plaster. The apex of the angle is straight and solid, to form a true corner.

A cornerite for reentrant angles is a narrow strip of metal lath (expanded, or wire), which is bent to fit around the corner. It is securely fastened to both walls, on which it extends from 3 to 6 inches. It acts as additional reinforcement for the plaster, so that the corner may be made as strong as any part of the surface.

The use of cornerite to protect a reentrant angle will enable the plaster to withstand greater stress before it cracks. Unfortunately, the amount of stress developed in the plaster is dependent upon the nature of the materials of which the wall is built, and upon the weather conditions to which it is exposed, and is thus beyond our control. We have no assurance that it will not reach a magnitude greater than the plaster can withstand, even with cornerite. When this occurs, instead of being confined to the corner, the crack is apt to spread in a branching formation over a considerable area of the wall, but with such a movement, the plain corner would also show a correspondingly large crack which would not necessarily be confined to the corner alone.

In a similar way, corner bead will afford additional protection to enable projecting corners to withstand slight impacts. But if the force of the impact is too great, the entire corner will be shattered, whereas, if no corner bead had been used, it is probable that the blow would have merely gouged out a small piece of plaster, which could have easily been repaired. The builder has no assurance as to the magnitude of the impact which the corners may be called upon to withstand. Where especially severe conditions are anticipated, corner beads may be made of No. 12 sheet steel. When properly anchored to the masonry walls with metal straps or toggles, they can be used as grounds for plastering, but should be grouted with a bed of plaster.

V. PLASTERING MATERIALS.

1. GENERAL PROPERTIES.

The properties of any plastering material must be considered in three states in order to determine its value. When in the plastic state, can it be spread into position without requiring an impractical amount of care and effort from the artisan? Does it harden quickly enough to prevent undue delay in the building operation, and is the shrinkage which normally accompanies the hardening small enough to be negligible? How closely do the properties of the hardened material approach those desired?

2. INGREDIENTS USED IN PLASTER.

The essential constituents of plaster are usually a cementitious material, inert aggregate, and water. For some special purposes the inert aggregate may be omitted.

The duration of the hardening process and the ultimate hardness of the plaster depend upon the kind and quantity of cementitious material used. The properties of the cementitious material and the aggregate, and their relative proportions, determine the ease with which the plaster can be applied. In the large majority of cases, the cementitious material is either lime or gypsum. Sometimes a mixture of the two is used; sometimes the lime is tempered with a little Portland or Keene's cement; and sometimes Portland cement is tempered with a little lime.

Water is necessary to develop the plasticity of the cementitious material, and to take part in the chemical reactions involved in the hardening process.

The amount of water which must be added to a cementitious material to develop the required workability is far in excess of the amount required chemically for the hydration of the material. In a "neat" plaster (one containing no aggregate) this excess water forms a large proportion of the total volume. If this water is allowed to evaporate before the plaster has hardened, pronounced shrinking of the mass as a whole is inevitable, even though the hydration of the cementitious material, considered alone, may be accompanied by expansion. When sand is added to the plaster, the relative proportion of water to cementitious material need not be changed, but the ratio of the volume of the water to the total volume of the plaster is very much diminished. The shrinking caused by evaporation of the water may thus be materially reduced to the point of practical elimination. For this reason, an inert aggregate must be regarded as an essential constituent of plasters, excepting only those which harden before the excess water has had time to evaporate.

Hair or fiber may also be considered as an aggregate, but it is used for a different purpose. It acts as a kind of reinforcement for the plaster while in a plastic state. When plaster is pushed through the lath, it sags down and clinches around the lath. When no hair is used, there is a tendency for the plaster to break instead of sagging.

3. LIME.

Quicklime is made by heating limestone to a temperature of over 900° C. It consists essentially of calcium oxide or of calcium and magnesium oxides. It comes in the form of white lumps, and is sold either in bulk or in barrels holding 180 or 280 pounds net each. When exposed to the air, lump lime will not keep. It must be kept in air and moisture proof containers, or slaked immediately upon receipt.

When water is added to quicklime, a chemical reaction ensues. The calcium oxide is converted to calcium hydroxide, and the magnesium oxide may or may not be converted into magnesium hydroxide, depending upon how hard it was burned. This reaction is known as slaking. If an excess of water is used, lime putty results. In this form, lime may be stored indefinitely provided only it is protected against drying out. The value of quicklime depends very largely upon its being properly slaked, and different kinds of lime require radically different treatments to get the best results. Full details on this subject are given in the specifications.

Hydrated lime is made from quicklime by slaking it with just enough water so that the chemical reactions are completed, but there is no excess. It comes in the form of a dry, white powder, and is sold in paper bags holding 50 pounds each. It will keep indefinitely, provided only that reasonable care is taken to protect it from the weather. Lime putty is made from hydrated lime simply by adding water.

When lime putty is exposed to the air, it first loses water by evaporation. This drying is accompanied by a decided decrease of volume. It then combines with the carbon dioxide of the air, which unites with both the calcium and magnesium to form the respective carbonates. Upon the interlocking of these carbonate crystals depends the strength of the hardened material. A peculiarity of this reaction is that it will not occur unless there is a small amount of water present, so that lime plaster will not harden properly under excessively dry conditions. On the other hand, the presence of too much water will prevent the proper interlocking of the crystals; the lime will be converted to carbonate just the same, but the mass will have no strength. Lime plaster will not harden properly when it is excessively and continuously damp. Fortunately these limits are quite wide, so the excessive dryness and dampness are of academic interest rather than practical importance.

Another peculiarity of lime is that no water is actually used in the hardening process. Not only the free water contained in the lime putty must be evaporated, but even that which is chemically combined with the lime must be replaced by carbon dioxide and evaporated before the plaster becomes thoroughly hard and dry.

The final product, calcium carbonate (with or without magnesium carbonate), is not easily affected by either water or heat. Its relative insolubility is illustrated by the known resistance which limestone offers to weathering. The high temperature required to make lime from limestone indicates the ability of lime plaster to withstand the action of heat.[1]

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[1] The ability of a plaster to withstand the action of heat must not be taken to indicate its value as a fire-resistive material. See Section VIII, 1.

Both quicklimes and hydrates are divided commercially into two grades on the basis of plasticity—masons and finishing. Finishing lime possesses plasticity in a higher degree than any other building material; the artisan can work finishing lime under conditions which preclude the use of any other cementitious substance.

Calcium carbonate is composed of a strong base and a weak acid. When dissolved in water and ionized, it gives an alkaline reaction. Lime plaster, therefore, becomes weakly alkaline when it gets wet. This characteristic is an aid toward preventing the corrosion of metal.

Quicklime shall conform to the requirements given in the current specifications issued by the American Society for Testing Materials, No. C5. It may be either screened or unscreened, lump or pulverized, calcium or magnesium. It shall be slaked in accordance with the directions given in the appendix to the above specification.

Hydrated lime shall conform to the requirements given in the current specifications issued by the American Society for Testing Materials, No. C6. Section A of these specifications applies to masons hydrate; section B to finishing hydrate.

4. GYPSUM.

Gypsum is a native rock, composed essentially of calcium sulphate crystallized with about 20 per cent of water. When heated to about 110° C. three-fourths of this water is readily driven off. The product is known as "stucco" at the mill; the trade knows it as "plaster of Paris"; according to the most modern nomenclature it is called "calcined gypsum."

When water is added to calcined gypsum, the solid material first dissolves and then crystallizes out in the form of the original gypsum, taking some of the water with it. The strength of the set material depends upon the interlocking of these crystals of gypsum.

The comparatively great solubility of calcined gypsum in water makes this hardening reaction take place quickly. It is usually complete in 10 minutes. However, the ability to control the time of set at the will of the artisan is one of the most important properties of gypsum. An organic compound similar to glue is sold under the trade name of "commercial retarder." One-fourth of 1 per cent of this material added to calcined gypsum is enough to retard the hardening for about two hours. If this is not available, ordinary glue will work just as well.

Calcined gypsum sets so quickly that the reaction is complete before the water gets a chance to evaporate. It can, therefore, be used in excessively dry locations. It will not harden properly in places where it is excessively and continuously damp, because the water will interfere with the proper interlocking of the crystals.

The rather high solubility of gypsum, and the comparatively low temperature at which it is decomposed, indicate that it is not very resistant to the action of either water or heat.[2]

Calcined gypsum is a white powder, which is usually shipped in barrels holding 230 pounds net each. It will keep indefinitely if reasonable precautions are taken to protect it from the weather. It is used in the plastering trade to gauge lime putty for the finish coat, to run moldings in place, or to cast decorative objects to be attached to the plaster.

Calcined gypsum shall meet the requirements of the current specifications issued by the American Society for Testing Materials, No. C23. It may be gauging plaster, molding plaster, or casting plaster.

Some calcined gypsum is used as such in the plastering trade, but a much greater amount is used as the base in preparing "hard-wall plasters."

If to calcined gypsum is added about one-sixth of its weight of hydrated lime to improve its plasticity and enough retarder to make it set in about two hours, the product is gypsum neat plaster. This is the chief gypsum product for the plastering trade. It may be had either fibered or plain. Going one step further, gypsum ready-sanded plasters contain all the necessary ingredients, except water, for either scratch coat or brown coat work. Sometimes a shredded wood fiber is used instead of sand, the product being designated gypsum wood-fibered plaster. Neat gypsum plaster is sold in cloth bags holding 100 pounds each.

Calcium sulphate is the compound of a strong base and a strong acid. When dissolved and ionized it may, under certain conditions, show an acid reaction. The use of hydrated lime in the manufacture of gypsum plaster gives assurance that the solution will at all times be alkaline.

Gypsum plasters shall meet the requirements of the standard specifications issued by the American Society for Testing Materials, No. C28—21.

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[2] See footnote 1, p. 21.

5. PORTLAND CEMENT.

Portland cement is made by heating a natural or artificial mixture of limestone and clay to above 1,200° C., or until it has begun to melt. The partially vitrified material is ground to a fine powder and mixed with a small amount of gypsum to retard its set. It is shipped in cloth or paper bags, holding 94 pounds each.

Portland cement is essentially a mixture of various silicates and aluminates of calcium. When water is added, the aluminates start the reaction by undergoing decomposition. Some of the calcium is split off and crystallizes out as hydrated lime. Some of the aluminate combines with the gypsum to form crystals of calcium sulpho-aluminate. The different kind of calcium aluminate which remains dries down into a tough, hornlike mass, which contains an indefinite amount of absorbed water. These reactions are followed by similar ones on the part of the silicates, the whole requiring a considerable period of time to go to completion. The final product consists of crystals embedded in an amorphous material, both the crystals and matrix containing water as a major constituent.

Portland cement uses a large amount of water in its hardening process and for complete hydration a sufficient supply of water must be maintained for many days. The conditions to which wall plaster is ordinarily subjected are not those which are best adapted to developing the full strength of Portland cement. On the other hand, and for the same reason, Portland cement is peculiarly adapted for use as a plaster under continuously and excessively damp conditions.

The resistance of hardened Portland cement to the action of water is too well known to require any further description. When heated,[3] its strength gradually diminishes with increasing temperature and time. Since one of the products of the hydration of Portland cement is hydrated lime, the hardened material will have an alkaline nature.

Portland cement shall meet the requirements of the standard specifications issued by the Federal Specifications Board, No. 1. These same specifications are also approved by the United States Government, the American Society of Civil Engineers, and the American Engineering Standards Committee.

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[3] See footnote 1, p. 21.

6. KEENE'S CEMENT.

Keene's cement is made from gypsum. Calcined gypsum is produced by heating gypsum to such a temperature that three-fourths of its water is driven off. If the temperature is raised somewhat, or the heating continued for a longer time, all the water will be driven off. The product, dead-burned gypsum, when mixed with water, will recrystallize in the form of gypsum, and develop hardness due to the interlocking of the crystals. It is so nearly insoluble, however, that this reaction takes place very slowly. A small amount of some chemical, such as alum, is therefore added as an accelerator, and the product is sold as Keene's cement.

When Keene's cement hardens, the final product is the same as that obtained from calcined gypsum. (See Section V, 4.)

7. SAND.

Sand is the chief constituent of plaster. Because of its comparatively low cost and wide distribution, not much attention has been paid to its quality.

It is generally accepted that sand shall all pass a No. 3 sieve; anything coarser than this is gravel or crushed stone. It is likewise coming to be accepted that all sand shall be retained on a No. 100 sieve; anything finer than this is clay, loam, or silt.

Natural sands are usually grains of quartz, but sand is not necessarily siliceous. Ground rocks of almost any kind make good plastering sands if they are properly screened. The rock should not contain noticeable amounts of pyrites or similar iron-bearing minerals which might stain the plaster. Common salt and other substances which are quite soluble are apt to cause trouble. They may combine with some of the other ingredients to form deliquescent materials which will prevent the plaster from drying out; or they may leach through to the surface and crystallize there as the water evaporates, producing efflorescence.

The idea that the sand grains should be angular instead of round is expressed in many of our building codes. While there is a possibility that the points of the grains may permit better attachment of the cementitious material, the fact remains that a satisfactory plaster can be made with round-grained sand.

Sand shall meet the requirements given in the current specifications for gypsum plastering sand, issued by the American Society for Testing Materials, No. C35, except that the requirement that 80 per cent of the sand shall be retained on a No. 50 sieve shall be regarded as an ideal to be approached rather than a rule to be enforced. While this specification is designed for sand for use with gypsum, the same kind of sand is satisfactory for use with other materials.

8. FIBER.

As stated above (Section V, 2) the only function of fiber is to enable the artisan to get the plaster spread in place without losing too much of it through "dropping." Obviously, it makes no difference whether the fiber is of animal or vegetable origin. It should be long enough to serve its purpose (one-half inch), but not so long that it will get tangled up (2 inches). It should be flexible enough so that it will stay buried in the plaster. It should be clean, for dust in the fiber is the same as dust in the sand. Above all, it must be evenly distributed throughout the plaster, and not occur in bunches.

9. WATER.

Sea water, or water commonly known as brackish, sulphur, chalybeate, or carbonated, shall not be used for plastering. The dissolved salts which they contain will cause deliquescence, efflorescence, or similar troubles.

With the above exceptions, any ordinary water may be used. Allowance must be made, however, for the effect which the dissolved salts may have on the time of set of gypsum.

10. READY-MIXED PLASTER.

Ready-mixed (dry) plasters can be obtained made with either gypsum or lime, and containing all of the ingredients, except water, necessary for either scratch or brown coat. Where the delivery cost is not excessive, they offer many advantages. Being mixed by machinery and under expert supervision, they are more nearly uniform and homogeneous than plasters mixed by hand at the work. Any defect due to proportions of ingredients can be placed squarely upon the manufacturer, provided, of course, that nothing but water is added to the plaster after delivery. The quality of the sand used in these plasters is selected so that it is usually better than can be obtained locally. The great drawback is the cost of transportation. If a reasonably good sand can be had locally, it is poor economy to pay freight on a ready-mixed plaster.

11. READY-MIXED MORTAR.

Ready-mixed lime plaster to which the water also has been added is now to be had in a few cities. It is sold as "ready-mixed mortar," being equally serviceable as either mortar, plaster, or stucco. It is delivered in tight-bottom trucks and dumped at the work ready for use. Where this material is obtainable, its use has many advantages. The architect and the contractor are relieved from all responsibility in regard to the purchase, storing, proportioning, and mixing of the various ingredients. The lime putty is more thoroughly aged, and the mixing more thoroughly done than could be accomplished at the work. The manufacturer is responsible indefinitely for the quality of the plaster in so far as that depends upon the quality and proportion of the materials. The labor and equipment necessary to mix plaster at the work are done away with.

Of course, ready-mixed mortar can only be delivered locally; it can not be shipped by freight. In spite of the advantages enumerated above, its value is finally determined by whether or not the delivered cost is lower than it would cost the contractor to buy the ingredients and mix the plaster himself.

VI. PROPERTIES OF THE WET MIX.

1. PLASTICITY.

Any of these cementitious materials consists chiefly of extremely fine particles. Most of them are so small as to pass through the finest sieve specified—the No. 200. Because of their fineness, they are the most active and, therefore, the most important part of the material. Some of these particles are crystalline; when examined under the microscope they are seen to refract light in certain definite ways. It is possible, however, to have a particle so small that its crystalline properties can no longer be detected, although the particle itself can still be seen with a microscope. It has been found that when particles reach this state of fineness they all have certain properties in common, regardless of their composition. For convenience, they have been grouped together under the name of "colloids." It is axiomatic that the smaller a particle is, the larger is its surface in comparison with its volume. A typical characteristic of colloids, therefore, is the enormous surface which they present.

While it is difficult to prove the exact behavior of a colloid under given conditions, the procedure may be visualized as follows: Imagine a single particle of hydrated lime, of colloidal size, immersed in water. The first effect is that the water attacks the surface of the particle, forming a gelationus emulsion. If there is enough water, this emulsion will diffuse away from the particle, and the final result will be a solution of the lime in the water. When there is just enough water to form an emulsion this will be held in place by surface tension, and will form an envelope surrounding the particle. The amount of water required to do this is not very definite, for the emulsion may be more or less dilute. Lime putty may be visualized as being made up of a large number of these particles, each separated from its fellows by its little envelope of milk of lime. Evidently, then, when external force is applied to such a putty, it will yield easily—the enveloping liquid acts as a lubricant, which is more or less viscous, depending on its concentration. When external suction is applied to such a putty, it will be found very difficult to reduce the water below a certain amount. Surface tension is a very powerful force, so that it is extremely difficult to withdraw enough water to break the envelopes. The putty, therefore, yields readily to applied force and holds its water strongly against applied suction. These two properties are combined in the meaning of the word "plasticity." Of the two, the second is the more important. It is well illustrated by the application of a finish coat to a hardened and partially dry brown coat. The brown coat is continually trying to suck the water out of the plaster being applied. If it is successful, the concentration of the emulsion forming the envelopes will be increased; the lubricant will become more viscous; and the plaster will be harder to spread. Finally, the envelope may break. This point is definitely recognized on the wall—the plaster may be torn, but it can no longer be spread. If the ability to hold water against suction is the same for two plasters, or if they are used under such conditions that this property is not important, as in scratch coat on lath, they may still differ in the amount of work required to spread them. This will depend upon the viscosity of the emulsion in the envelopes, which is in turn dependent partly upon its concentration and partly upon the nature of the solid and liquid of which it is composed. The well-known effects of temperature, consistency, soluble salts, etc., may thus be accounted for.

When these little colloidal particles are brought into actual physical contact with each other, they are apt to amalgamate. Their diameters are so very small that the force of gravitation becomes an important aid to cohesion. If enough of them are stuck together in this way, the resultant aggregate will behave like a single particle. It may be much larger than a crystal of the same material, and yet have no crystalline properties. Such a particle presents much less surface to the water than would be presented by the individual particles of which it is composed. It thus reduces the amount of lubricant in a given volume of putty. Moreover, these particles are usually very irregular in shape, so that still more resistance is offered to their moving over each other. For both of these reasons, the more the colloidal particles have been grouped together in aggregates, the less plastic will the material be.

The process of uniting colloidal particles into aggregates is known as flocculation. Fortunately, flocculation is not usually automatic; it requires some external force to bring it about. Once it has occurred, however, some other force is required to deflocculate the particles again. The agents chiefly used to bring about flocculation are heat, the electric current, or soluble salts. During the manufacture of hydrated lime, if the conditions are such as to produce a rather high temperature, the particles are flocculated, and the product is a mason's hydrate, not plastic enough to be used for finish. The initial products of hydration of Portland cement are colloidal, but the strongly alkaline solution flocculates them almost as soon as they are formed.

In a finishing hydrate the particles are in the form of aggregates, but the cohesion is weak. When the hydrate is soaked in water the aggregates break up and water gets in to form envelopes around the individual particles. A finishing hydrate is therefore not very plastic until after it has been soaked for some time. In a mason's hydrate, the aggregates will not yield to soaking in any practical length of time. It has recently been discovered by F. C. Welch, of the Bureau of Standards, that they can be broken up by grinding them with a small amount of a desiccating agent, such as quicklime. The resultant product is plastic.

Gypsum, as usually prepared, is in the crystalline form, and is not plastic. If it is ground under conditions such that none of its water is lost, it can be reduced to a colloidal condition, and is then plastic.

Plasticity, as the mark of distinction between finishing and mason's hydrate, has some commercial importance. For some purposes, such as finish-coat work, a certain degree of plasticity is essential, else the material is useless. In all plastering work plasticity has an important bearing on the labor cost. An instrument based on the principles outlined above is now in use for the measurement of plasticity. It is described in Bureau of Standards Technologic Paper No. 169, and its use is included in the specifications for finishing hydrate cited above (Section V, 3).

2. WATER-CARRYING CAPACITY.

By this term is meant the relative amount of water which must be added to the dry material in order to bring the mixture to such a consistency that it can be used for plastering.

Part of this water may be considered as going to make up the envelopes which surround the grains, and may, therefore, be called "colloidal water." The rest of it fills the voids between the grains, and may be called "free water." The difference between these two kinds of water is, of course, imaginary and not real; they are named only as a matter of convenience.

As between two lots of material, one of which consists of individual colloidal particles and is plastic and the other of aggregates of colloidal particles and is not plastic, evidently the former would require the more colloidal water, because of its greater surface. On the other hand, the irregular shapes of the aggregate prevent them from fitting together so nicely as the individual particles, and hence they will require more free water to fill the voids between them.

The water-carrying capacity is therefore not a safe means for judging the relative plasticities of two materials, unless assurance is had that the particles of both materials are in the same physical state.

3. SHRINKAGE.

The decrease in volume of a plaster before it has hardened has an important bearing on its further value. This question has been discussed in Section V, 2, above.

4. SAND-CARRYING CAPACITY.

The shrinkage of cementitious materials would be a serious drawback were it not so easily overcome by the addition of sand. If the proportion of sand is so regulated that when the plaster is in position the sand grains are in contact with each other, the interstices between them being filled with cementitious material, there can be no shrinkage. If more sand is used, the voids will not be filled with cementitious material, and the plaster will be lacking in strength. If less sand is used, the grains of sand will not be in contact with each other, and the plaster will shrink. It is safer to use a little too much rather than not enough sand, for a slight sacrifice of strength will not make much difference, whereas shrinkage will cause cracks which are immediately noticeable.

A fine sand, or one containing too much fine material, will have a large number of small voids. It has been found very difficult to get these voids filled with cementitious material, so that a sand of this kind will make a weak plaster and should not be used. If the sand is all coarse, the voids will be so large that the cementitious material will shrink away from the grains of sand. The best quality of sand is that specified above (Section V, 8).

Individual colloidal grains of cementitious material are of such a size and nature that they can readily be worked into the spaces between the sand grains. When the colloidal grains are aggregated, they are no longer available for this purpose. The aggregates may even be larger than the sand grains and, therefore, tend to increase the voids rather than fill them. The more individual colloidal grains which a cementitious material contains, the better able will it be to fill the voids in the sand and, therefore, the less of it need be used. In other words, the greater the plasticity the greater the sand-carrying capacity.

This relation between plasticity and sand-carrying capacity has long been recognized in the plastering trade. It is customary to add as much sand as possible and still have the plaster "work right." It has been found, however, that this method of proportioning is not safe. When the measurement is made by an unskilled laborer, as is usually the case, and when he is working under pressure caused by the cheapness of sand in comparison with the cementitious material, the result is practically always the use of too much sand.

The testing machine which has been developed to measure plasticity (see Section VI, 1) can also be used to measure the working quality of a sanded plaster. By this means it has been found that a certain amount of sand can be added to a cementitious material without seriously affecting its working quality, but a small additional quantity of sand changes the character of the mixture from that of the cementitious material to that of the sand. This point seems to be quite definite, and obviously corresponds with the practical definition of sand-carrying capacity mentioned in the preceding paragraph.

It is understood that this definition is intended to set up a standard rather than to specify quantities for use. Having

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measured the "sand-carrying capacity" of a given cementitious material, more or less of the material may be used, depending upon whether greater strength or less shrinkage is the more to be desired.

The sand-carrying capacity varies not only with different kinds of cementitious material, but also with different brands of the same kind and with different kinds of sand. The practical application of this definition, therefore, offers serious difficulties.

For the present, therefore, it is safer to specify arbitrary proportions of sand and cementitious material. The above discussion does lead to one emphatic conclusion—the proportioning of sand for plasters is sufficiently important and delicate to justify careful supervision.

5. TIME OF SET.

The time of set of a plastic material has an important bearing on the cost of the finished wall. If it sets too quickly, it can be mixed in small batches only, and even then a good deal of it is apt to be wasted because it has set before the plasterer has had time to use it. The laborer who does the mixing will have to spend too much of his time in cleaning out the mortar box. If it sets too slowly, careful planning of the work must be carried out, or else the plasterers may have to stand around waiting for one coat to set before the next can be applied. In extreme cases it may even be found necessary to move the scaffolds in order to save the plasterers' time.

This property is particularly important in the finish coat. This coat must be troweled just as it begins to set. It is made up of cementitious materials only and is therefore bound to shrink If it is troweled before set has occurred, it will continue to shrink, and crack. It can not be troweled after set has occurred, for the particles are then too rigid to yield to the trowel. The plasterer tries to have it set in just the time that it will take him to spread it over one wall. If it sets more quickly than this, he will have to stop in the middle of the wall and go back to take care of it. If it sets more slowly, he will have to wait around for it after the wall is covered.

The time of set as measured in the laboratory is an empirical quantity, dependent upon the method of measurement. There are standard methods for measuring the time of set of cement and of gypsum. While these methods are satisfactory for comparing times of set of different samples, they are not of much use in indicating how the material will behave as a plaster. In the cement method the consistency is very much drier than could be handled with a trowel, and the use of a different proportion of water has a decided effect on the time of set. The shape, size, and condition of exposure of the test specimen are quite different from those of the plaster. Even the definition of the word "set" is different. A plaster is said to be set when it is hard enough to receive the next coat, but it may still be too soft to withstand the Vicat needle used in the laboratory.

A laboratory method more closely analogous to practical conditions than the methods now in use is as follows: Mix the material with enough water so that when molded in the form of a cylinder 2 inches in diameter by 4 inches high and the mold immediately removed it will slump to a final height of 3½ inches. Mold this mixture in the form of a slab, 4 inches square by one-half inch thick, on a base of metal lath. Scratch the surface, making grooves about one-eighth inch deep. Remove the mold and support the specimen in such a way that there is a free circulation of air around all six sides. The material is "set" when the edges of the grooves are able to withstand the pressure of the thumb. When tested by this method, a scratch or brown coat of gypsum or cement will set in from 1 to 4 hours; a finish coat of lime and gypsum in 20 to 30 minutes.

As stated above, the time of set is chiefly of economic importance and, in the case of gypsum, may be varied at the will of the operator. Therefore, so long as it is within such limits as to assure good quality of material, rigid adherence to the figures given in the specifications is not necessary.

VII. MIXING AND APPLICATION.

1. STORING OF MATERIALS.

The addition of water to any of the cementitious materials used in plastering starts the hardening reaction. Precautions must, therefore, be taken to keep them dry until used. Do not store them directly on the ground, nor pile them next to damp walls. A good roof is, of course, necessary, and it is advisable to prevent circulation of air around the material. This latter precaution must be observed in the case of quicklime.

2. WEATHER CONDITION.

The ideal atmospheric conditions for plastering are warm and humid. Plaster shall not be applied to a masonry wall containing frost, nor under such conditions that the plaster may freeze before it has a chance to harden. Very damp and cool conditions may interfere with the proper hardening of lime and gypsum temporarily, but the effect will not be permanent unless the conditions persist. Very dry and hot conditions are bad for all kinds of plaster. The rapid evaporation of water is apt to cause excessive shrinkage, and it is quite possible for enough water to be lost in this way so that the amount required for the hardening reaction will not be present when needed.

3. MIXING METHODS.

Wherever the magnitude of the work will justify the overhead charges, plaster should be mixed by machine. Due to more thorough mixing, and better control of conditions, machine-mixed plaster is more uniform and of better quality than that mixed by hand.

When the ingredients of plaster do not require preliminary soaking, the dry materials shall be mixed thoroughly to uniform color. They shall then be added to the water (do not add the water to the dry materials unless a mixing machine is used) and mixed thoroughly to a uniform consistency. Use as little water as possible and still have the plaster of such a consistency that it can be properly worked. Any excess water may cause trouble, due to segregation, difficulty of application, loss of material as droppings, or excessive shrinkage.

Sometimes one of the ingredients must be soaked before being used, as in the case of quicklime, or in order to develop the full plasticity of a finishing hydrate. Directions for slaking quicklime and for screening and aging the putty are given in the appendix to the specifications for quicklime issued by the American Society for Testing Materials, No. C5. They shall be complied with in full.

When sand or Portland cement is to be added to lime putty, the mixing shall be done as follows: Reduce the putty with enough water so that it is a little too wet for use as a plaster. Spread this out in an even layer in the mortar box. Add the other material, spreading it in an even layer on top of the putty. Hoe to uniform color throughout. Do not add any more water unless it is absolutely necessary.

A mixture of finishing hydrate and calcined gypsum to be used for finish coat shall be prepared as follows: At least one and preferably two days before the coat is to be applied mix the hydrate with water to a rather thin consistency. Cover with a damp cloth and let soak until ready to use. When ready to apply, circle out some of this putty on the mixing board. Fill the circular space surrounded by the putty to about one-third its depth with water, and sift into it enough calcined gypsum to make a putty of about the same consistency as the lime putty. Mix the two thoroughly with a trowel, and use immediately.

If the plaster contains either Portland cement or gypsum, do not mix more material than can be used in one hour, for scratch or brown coats, or one-half hour for finish coat. Clean the mixing box and the tools carefully before mixing a fresh batch, throwing away all material which has begun to set. Gypsum can not be retempered; if it is used after it has appreciably hardened the plaster will have no strength. Set gypsum is a very efficient accelerator for calcined gypsum. It is particularly important, therefore, to clean the mixing box and tools thoroughly after each batch, in order that the time of set of the fresh batch will not be accelerated so much as to make the material useless.

In case it is necessary to interrupt the application of plaster in order to mix a fresh batch of material, work should be stopped at some natural line on the surface, such as an angle, a window or door opening, etc.

4. GROUNDS.

Ground strips are narrow strips of wood or metal placed around and parallel to the edges of a surface to be plastered and all openings therein. They are attached to the backing. They were originally designed to be used as guides for a straightedge, to bring the brown coat to a true and even surface. The thickness of these ground strips, therefore, governs the thickness of the plaster. Sometimes the strips are covered with the wood trim; sometimes they are removed after the brown coat has been straightened, and the spaces which they occupied are filled with plaster; sometimes they are not used at all. In any event, they are never visible in the finished work.

From the use of these strips, the term "grounds" has come to mean the thickness of the plaster.

Planed 1-inch lumber is approximately seven-eighths of an inch thick. This, therefore, was found to be a convenient dimension for ground strips, and was generally adopted. It is still universally specified that the grounds for three-coat plaster on lath shall be seven-eighths inch. When the number of coats is reduced, or the plaster is applied to masonry instead of lath, the different conditions make it desirable to change this dimension of the grounds.

Spot grounds are sometimes used. They are pieces of wood attached to the backing at intervals.

While the primary function of plaster on lath is undoubtedly decorative, its other functions are too important to be neglected. A lath and plaster structure, whether it be a partition, a ceiling, or the inner surface of the wall of a frame house, must have certain properties—it must be sufficiently rigid to withstand ordinary abuse. It must be acoustically absorbent, in order that disagreeable echoes be eliminated and that sounds shall not be transmitted from room to room through the building. It must have a certain amount of fire resistance, to afford protection to the structural members behind it, and prevent the spread of fire. It must offer some obstruction to the passage of heat, in order that the building may be economically heated, and to prevent moisture from condensing on the wall.

Fortunately, all of these requirements are met by the same condition. For a given type of plaster applied to a given type of backing, its rigidity and its ability to resist the passage of sound, fire, and heat are all dependent upon its mass. The thicker the plaster, the better. Certain practical considerations limit the application of this theorem. It would be impractical to make plaster more than seven-eighths inch thick without introducing a fourth coat. Both material and labor costs would thus be increased. The weight of hardened plaster may be taken at about 100 lbs./yd.^{3} Plaster thus forms an important proportion of the load which the structural members of the building are expected to carry. This is particularly true of the plaster on ceilings. Any increase in the thickness of the plaster would increase the weight proportionally. This would certainly require the use of heavier lath, and might necessitate strengthening the structural members throughout the building.

Inasmuch as a thickness of seven-eighths inch has been generally adopted for plaster on lath, and has been found convenient and satisfactory, it is recommended that this dimension be continued in use. The practical difficulties attendant upon increasing this thickness are probably great enough to offset any advantages which might ensue. The grounds for plaster on lath shall not be less than seven-eighths inch.

When plaster is applied directly to masonry, its ability to resist the passage of sound, fire, and heat becomes of minor importance in comparison with the resistance of the masonry. The plaster must, of course, be able to withstand ordinary abuse, but in this case its strength is dependent mostly upon the hardness of the surface, the necessary rigidity being supplied by the masonry. The surface hardness depends upon the composition of the plaster and not upon its thickness. For these reasons, plaster on masonry is to be regarded almost exclusively from the viewpoint of its decorative value.

The masonry surface to which plaster is to be applied must be rough, in order that proper adhesion be assured. (See Section III, 3.) It is first necessary, therefore, that a sanded coat of plaster be applied, to fill up the depressions in the masonry and bring the wall to a true and plane surface. A finish coat, for decorative effect, may or may not be applied, at the option of the architect.

The first coat must be sanded. The depressions in the masonry are apt to be of such size that they will hold considerable volumes of plaster, and the shrinkage will be correspondingly great unless the plaster is sanded. Moreover, this first coat should have as nearly as may be the same coefficients of expansion as the masonry in order to lessen differential movements and cracking. It is necessary to trowel down the scratch coat with sufficient pressure to insure good bond between the plaster and the masonry. This can be accomplished with greater facility when the coat is thin rather than thick.

For the above reasons and also because there is nothing to be gained by using a thicker coat, it is recommended that plaster on masonry be no thicker than is required to produce a true and plane surface.

5. FUNCTIONS OF DIFFERENT COATS.

Plaster is applied in not more than three coats, which are designated "scratch," "brown," and "finish."

The scratch coat is applied first. Its primary function is to act as a bonding coat to attach the body of the plaster securely to the lath or masonry. The properties required of a scratch coat are evidently dependent upon the nature of the backing to which it is to be applied.

When applied to lath, the scratch coat must have sufficient plasticity and cohesion so that it can be worked through the openings and curl down behind to embed the lath. Quick hardening is desirable, in order that the work be not unnecessarily delayed.

When the coat has hardened, the structure composed of lath and scratch coat must exhibit considerable rigidity. Otherwise, when the plasterer applies the brown coat, the pressure of his trowel may cause sufficient deflection to destroy the bond between the lath and the scratch coat. The scratch coat must be thick enough to cover the face of the lath, and must be roughened to provide a bond for the brown coat. The chief requirements are, therefore, plasticity and cohesion of the wet plaster, quick hardening, and strength of the hardened plaster.

When scratch coat is to be applied to masonry, it must have sufficient plasticity so that it can be worked into the depressions, but the cohesion of the wet material is of minor importance. Quick hardening is desirable, and it is extremely important that the hardening be accompanied by as little shrinkage as possible. The coefficients of expansion of the hardened material should be as nearly as possible the same as those of the masonry. Strength is not so important as hardness. The surface should be true and plane. The decorative finish may be attained by treating the scratch coat, or a finish coat may be used.

The brown or second coat forms the main body of plaster on lath. For a given type of plaster on a given type of lath, the resistance of plaster to the transmission of heat, fire, and sound, which is largely dependent upon the mass of material they have to penetrate, is governed primarily by the thickness of the brown coat. Since the depressions in the scratch coat are made of such a form that they are readily filled, there is no great need for plasticity in the brown coat, nor is any great amount of cohesion required of the wet material. Quick hardening is not so important, as for scratch coat, because it is customary to allow sufficient time for the thorough hardening and drying of the brown coat before the finish coat is applied. The decorative finish may be attained by treating the brown coat, or a finish coat may be used. The brown coat must, therefore, be sufficiently hard to form either the wearing surface of the wall or a solid backing for the finish coat. It should be remembered that the richness of plaster (high content of cementitious materials) will be accompanied by high shrinkage. It is essential, therefore, that the brown coat be not richer than the scratch coat to which it is applied. Otherwise, the greater shrinkage and strength of the brown coat will inevitably cause cracks, if it does not pull the scratch coat loose from the lath.

The finish, or third, coat is usually applied only when a smooth white finish is desired. This coat must be free from cracks, it must be hard enough to withstand reasonable abuse, and, above all, it must present a pleasing appearance. The functions of this coat are such as to put exceptionally severe requirements on it and thereby limit the compositions which can be used. In order to produce the desired hardness and the smooth white appearance an ordinary sanded material can not be used. A small amount of fine white marble dust or white sand is sometimes used, but it is better to make this coat of cementitious material only. Leaving out the fine aggregate will permit the shrinkage of the cementitious material to have full effect, and there is, therefore, a decided tendency for the finish coat to crack. This tendency is overcome in two ways—by making the coat as thin as possible and by troweling it at exactly the proper time. A thin coat contains less volume of material than a thick coat. The quantity of plaster which is actually bonded to the undercoat, therefore, bears a larger proportion to the total volume. The thin coat also permits troweling with greater facility. Both of these factors give greater assurance of uniform bond between the finish and brown coats, so that the shrinkage stresses are distributed and thereby divided. The tendency, therefore, is to form a large number of small cracks rather than a few large cracks. If the coat were thick, any attempt to close these cracks would result in a surface effect only, whereas with a thin coat they can be completely closed. The cracks are closed, or rather prevented, by troweling the finish coat just as the cementitious material is hardening. If it is troweled too soon, the plaster will continue to shrink (and crack) after the troweling; after it has hardened the cracks can not be closed. The time of set of the finishing coat is, therefore, very important. The plasterer starts at one side of the room and spreads the finish coat over the entire surface (except where scaffolds are necessary). He then goes back and trowels it down to a smooth finish. If the plaster sets too quickly, he may have to stop in the midst of the spreading operation to go back and trowel that which has been spread. This will leave an unsightly blemish in the surface, marking the line where he was interrupted. If it sets too slowly the plasterer will have to wait for it, which may result in serious loss of time. A dry, brown coat sucks the mixing water out of the finish coat very quickly. This is desirable because it produces maximum shrinkage in a short time, and when the cracks which this shrinkage would cause are prevented by troweling at the proper time, no further difficulty is to be expected. Since the finish coat must be applied in a very thin layer over a dry, brown coat, the plasticity of the material is exceedingly important. In fact, if the material is not sufficiently plastic, it is physically impossible to use it at all for finish coat work.

6. PROPORTIONS.

Practically all plaster consists of a mixture of at least two materials besides water. The proportions in which these dry materials are mixed is, of course, important in determining the properties of the plaster. Some attempt is usually made to measure the quantities of the different ingredients, and the importance of this operation is sufficient to warrant conducting it with considerable care and accuracy. The degree of accuracy used is, of course, governed by the cost, but it never pays to guess at the quantities.

One of the great hindrances to the establishment of definite methods of proportioning is the conflict of opinion as to whether the measurements should be made by weight or by volume. Contractors find volume measurements much more convenient. The ingredients used, however, vary considerably in the weight per unit of volume, even as between different lots of the same brand of the same material. Consequently, a specification calling for a definite volume of material, even if rigidly followed, would not insure the presence of a definite weight of that material in the finished plaster, particularly when the volume is measured "loose." On the other side, the arguments are that the cost of weighing the materials is so great as to be impractical; that the error introduced by proportioning by volume instead of weight, while admittedly large, is still small enough to be neligible; and that it is more important that the finished plaster shall contain a given volume of cementitious material rather than a given weight. The facts are, therefore, that the volume system is in universal use; that there are good reasons why a change should be made to the weight system, but there are also reasons why this change should not be made. It is therefore recommended that all proportions be expressed by volume, with the insistence that the contractor use reasonable care in making the measurements.

The proportion of water has the same effect on plaster as it has on cementitious materials used in other forms—the more water the weaker the hardened product. Fortunately, however, this factor is not of great importance in the plastering industry. The proportion of water is very narrowly limited by the conditions of use. Too little water will make the plaster difficult to spread;

too much water will make it slide off the trowel or wall. The "proper consistency" is, therefore, so closely defined that no further precautions are necessary.

The following proportions, by volume, are recommended for the different kinds of plaster. One volume of lime means one volume of either lime putty or dry hydrated lime. Gypsum means neat gypsum plaster. The proportions given are for "straight" lime, gypsum, or Portland cement plasters. Lime may be mixed with Portland or Keene's cement in any desired proportions. Portland cement shall not be mixed with Keene's cement or gypsum. For further information about these mixtures, see Sections VIII and XI.

Nothing except water shall be added at the work to ready-mixed mortar, ready-mixed plaster, or gypsum wood fibered, finishing or bond plasters.

For scratch coat on lath, use 1 volume of lime to 1½ of sand, 1 of gypsum to 2 of sand, or 1 of Portland cement to 3 of sand. In all cases, hair or fiber may be added in amounts not to exceed 3 bushels per cubic yard of sand.

For scratch coat on masonry, use 1 volume of lime to 3 of sand, 1 of gypsum to 3 of sand, or 1 of Portland cement to 3 of sand. If a finish coat is to be used, hair or fiber may be added to the scratch coat in amounts not to exceed 1½ bushels per cubic yard of sand.

For brown coat use 1 volume of lime to 3 of sand, 1 of gypsum to 3 of sand, or 1 of Portland cement to 3 of sand. If a finish coat is to be used, fiber may be added to the brown coat in amounts not to exceed 1½ bushels per cubic yard of sand.

For finish coat, the proportions of lime putty and gypsum shall be left to the discretion of the plasterer. He must add enough gypsum so that the material will set at the desired moment, and the proportion to be used will, therefore, depend upon the area of the surface to be plastered, and the weather. "Plastic gypsum," which is now on the market, can be used without lime for the finish coat. It is expected that "quick-hardening lime," which can be used without gypsum, will soon be available.

7. APPLICATION.

The scratch coat on lath shall be thoroughly trowelled to push the material through the openings in or between the laths. It shall be brought out to a reasonably true surface. It shall be of such a thickness as to cover the face of the lath about one-fourth inch. Before it has hardened, it shall be scratched with a suitable tool, making V-shaped scratches about one-eighth inch deep by 1 inch apart. These scratches shall be parallel, being horizontal on walls, but not necessarily continuous. The scratch coat shall be permitted to harden until pressure of the thumb is not sufficient to break down the edges of the scratches. It is then ready to receive the brown coat.

The scratch coat on masonry shall be thoroughly trowelled, to push the material into the depressions in the masonry. It shall then be built up to the desired thickness, and rodded to produce a plane true surface, flush with the grounds. It shall be permitted to set until thoroughly hard and dry, before applying the finish coat, or any other decorative finish.

The brown coat shall be thoroughly trowelled, to push the material into the depressions in the scratch coat. It shall then be built up to the desired thickness, and rodded to produce a plane true surface, flush with the grounds. It shall then be darbied to take out the irregularities left by the rod. Finally it shall be floated to take out the last of the irregularities and produce sufficient porosity to give the proper suction for the application of the finish coat. It shall be permitted to set until thoroughly hard and dry, before applying the finish coat, or any other decorative finish.

The finish coat shall be spread over the entire area of one surface which can be reached from one scaffold, or without a scaffold. It shall be spread as thin as possible without having the under coat show through, and there shall be no noticeable joints or ridges. After the designated area has been covered, the plaster is closely watched, looking along its surface toward the light. At a certain time, depending on the amount of gypsum used, the glaze due to the water on the surface will suddenly disappear, the surface becoming dull as the gypsum begins to crystallize. This is the proper time to trowel the finish. The plasterer brushes the surface with water, holding the brush in one hand and the trowel in the other, in order that the trowel may follow the brush immediately. It is essential that the plasterer use all the pressure he can apply to the trowel during this operation, and that the whole surface be gone over as rapidly as possible, without interruption.

"Doubled-up," "laid-off," or "laid-on" work, as it is variously called in different localities, means the application of the scratch and brown coats together, or at least without permitting the usual time to elapse between them. The scratch coat is applied in the way specified above, but it is not permitted to harden, nor is its surface scratched. The application of the brown coat is started immediately after finishing the application of the scratch coat. This method is obviously cheaper than straight three-coat work, but certain precautions are essential to its successful use. The brown coat must be applied before the hardening of the scratch coat has progressed far enough to produce a glazed surface. The backing must be sufficiently rigid of itself that it will not yield under the pressure of the trowel, and will not sag under the weight of the combined coats. If it deflects to any appreciable extent, the keys which hold the scratch coat to it will probably be broken, and if it sags, it will be found extremely difficult to bring the brown coat out to a true plane surface. For these reasons, doubled-up work shall not be applied to metal lath. Its use on wood lath is not recommended, particularly if the plaster is to be seven-eighths inch thick. On masonry backings the use of doubled-up work is largely a question of application—if the plasterer succeeds in making the plaster stick and is able to form a true and plane surface, the work will be satisfactory. This depends on the thickness of the plaster and the nature of the backing. It is difficult to apply a doubled-up coat of a thickness greater than five-eighths inch. The great suction exerted by gypsum tile makes the application of doubled-up work easy; on clay tile it is almost impossible.

8. EXPOSURE.

After the plasterer has completed his work, the plaster will normally be exposed to air which is at least above freezing, and which is at least not saturated with humidity. Water immediately starts to evaporate from the plaster. The amount of water which will be evaporated in a given time depends not only on the temperature and humidity of the air, but also on the quantity of air coming in contact with the plaster; that is, the circulation. The amount of water which must be evaporated will depend upon the amount put into the plaster (its water-carrying capacity) and the amount used up by the chemical reactions involved in the hardening process.

Lime has a high water-carrying capacity, and has no use for this water in the hardening process. In fact, the hardening of lime is accompanied by the loss of not only the mixing water, but also of that water which is chemically combined as calcium hydroxide as this substance is gradually converted to calcium carbonate. In order, therefore, that lime plasters may develop their full strength without undue loss of time, they should be exposed to warm, dry air, and the circulation of the air is more important (within limits) than its temperature or humidity. As previously noted, a certain small amount of water is required for the final hardening of lime plaster. Drying will accelerate the initial hardening, but, if carried to completion too soon, will have a deleterious effect on the ultimate quality of the product. Direct drafts, tending to cause local drying, should be prevented.

Gypsum requires much less mixing water than lime, and the hardening of the gypsum depends upon a chemical reaction which uses up nearly half of this mixing water. There is still some water left to be evaporated, but this is not enough to warrant taking any special precautions to get rid of it. With gypsum the disadvantage may be the other way—the mixing water may be evaporated so rapidly that there is not enough left to take part in the chemical reaction. When this happens the plaster will be "punky"; that is, it will be friable, with little bond or strength. This fault is easily obviated by adding some accelerator, which will make the gypsum harden before too much water has been evaporated, or the fault may be cured by rewetting the plaster.

Portland cement requires very little mixing water, but it requires a great deal of water for its hardening reactions. It differs from gypsum in that this necessary water must be available over a considerable period of time. For this reason it is always desirable to keep a cement plaster wet for several days after its completion. However, the purpose for which plaster is used makes it impracticable to keep it wet for more than a few days, so that it is seldom possible to develop in a cement plaster the full strength of which it is capable.

The wood trim is usually applied as soon as the plaster is sufficiently dry so that it will not liberate enough more moisture to warp the wood or blister the varnish. It must be remembered here that the terms "dry" and "hard" are by no means synonymous with either gypsum or cement plasters, though they may be with lime. Plasters will usually be hard long before they are dry enough to permit application of the trim.

VIII. PROPERTIES OF THE HARDENED PLASTER.

The most important property of any plaster is undoubtedly the decorative value, which will be dealt with separately in the next chapter.

1. FIRE RESISTANCE.

Unless plaster is especially designed for the purpose, its ability to withstand fire is not usually regarded as of any great moment. It is expected, however, that the plaster will always be ready to provide a short, though perhaps not sufficient time for the arrival of the fire-fighting apparatus. As long as the plaster stays in place, its ability to resist fire is dependent upon its ability to resist the passage of heat through it. If it offers sufficient resistance to the passage of heat, then the temperature of the structural members back of the plaster will not rise above the danger point, and the plaster will have served its purpose, even though it be ruined in the process.

The specific heat conductivities of the usual kinds of plaster are all so nearly alike that this factor is negligible as a basis for choosing between them. There are differences, however, based upon the endothermic chemical reactions involved.

The lime in a hardened lime plaster is present as calcium carbonate. This is decomposed by heat at about 900° C. (1,652° F.), and heat is used up by the reaction. The temperature of lime plaster, therefore, can never rise much about 900° C. (1,652° F.) as long as there is any calcium carbonate undecomposed. Unfortunately 900° C. (1,652° F.) is far above the danger point for either wood or iron, so that this reaction of lime plasters can afford no protection to the structural members.

With gypsum and cement plasters, however, the case is different. When exposed to fire, they both undergo endothermic decomposition, just as lime plaster, but the reactions begin at a temperature little higher than 100° C. (212° F.). The plaster must, therefore, be completely decomposed before the temperature of the structural members can rise high enough to cause serious injury.

Plaster is of value as a fire-resistive material only so long as it stays in place. The greatest problem, therefore, is to prevent it from cracking and falling off the wall or ceiling, when it is exposed to fire. The materials of which the plaster is composed expand when heated. Sudden, severe, local application of heat, as in a fire, will cause sudden, severe, local expansion. The only direction the plaster is free to expand is by bulging outward away from the wall. This quickly breaks the keys, or tears the lath loose and the plaster falls. This effect is perhaps magnified by the partial calcination of the cementitious material and by the peculiar differential expansion of the grains of quartz sand, both of which weaken the plaster and make it less able to resist the strains.

It seems that the nature of the lath is more important than the nature of the plaster, as tests made by the Fire Underwriters Laboratories and others indicate that cement or gypsum plaster on metal lath will afford one hour's protection to the wooden structural members behind the plaster.

2. HEAT CONDUCTIVITY.

About the only place where this property of a plaster is of any real importance is as an aid to the fire resistance, as described in the preceding section. It has already been recommended that the interior of all exterior walls be furred, and that suspended ceilings be used where the ceiling forms the under side of the roof. If one room of a building is designed to be kept at a temperature quite different from the one next to it, it would be logical to insulate the partition between the two. The heat conductivity of a wall, therefore, wherever it is of any importance, depends on the value of the insulation built into the wall, this insulation usually taking the form of an air space. The heat conductivity of the plaster is of minor importance.

3. ACOUSTICS.

When sound strikes a wall, it may be considered as divided into three parts—one part is reflected back whence it came, another part is transmitted through the wall and comes out on the other side, and the third part is absorbed, or lost inside the wall. The construction of the wall, and particularly of the plaster, governs the relative magnitude of these three parts, and they, in turn, determine the suitability of the structure.

In a lecture room, church, theater, etc., it is very important that very little sound be reflected, but it makes little difference how much is transmitted. In an office building or apartment house exactly the reverse is the case. In the best type of dwelling the partitions should be of such a nature as to absorb as much as possible of the sound which they receive.

Consideration of the acoustical properties of the materials commonly used in plastering leads to the belief that the differences as between lime, gypsum, or cement; or as between smooth troweled or sand float finish, are so small as to be practically negligible. Where these materials will not produce the desired acoustical properties we recommend the use of a wall covering of entirely different type.

The transmission of sound through a wall depends not only upon the plastering, but also on the nature of the wall itself. Other things being equal, less sound will be transmitted by a heavy wall than by a lighter one. Of two walls of equal weight, the thicker will transmit less sound. In figuring either weight or thickness the plastering may be included as part of the wall. A hollow wall is more effective except for the bridging than a solid wall in preventing transmission, provided the air space is introduced without sacrificing either the weight or the thickness of the solid material.

The acoustical properties of a wall (or ceiling) are not quite so simple as described above. Whatever the size of the wall may be, there are sounds of such pitches that their impact on the wall will cause it to vibrate with them. This will enormously increase the proportion of sound reflected. If the wall is of such a nature that the whole structure is set into vibration, the movement will generate sound on the other side of the wall. This difficulty can best be overcome by building the wall of sufficient rigidity or weight or thickness, so that it can be set in vibration only by sounds of very low pitch—so low that they seldom occur.

4. VOLUME CHANGE.

Heat or dampness will cause plasters to expand. Cold or dryness will make them contract. Since they are continuously subjected to changing atmospheric conditions, these movements are continuously going on. The movements are usually so small that they are negligible, but sometimes conditions arise which make the movements cumulative, resulting in continued, though interrupted, expansion or contraction.

These movements may be blamed almost wholly on the cementitious material, and indicate that the plaster is too rich. If the plaster is made sufficiently lean, and is well troweled, the grains of sand will be in actual physical contact with each other, the cementitious material occupying the interstices between them. The contraction of such a plaster would involve contraction within the sand grains, which is never a serious matter. The expansive force of the small amount of cementitious material is so well distributed, that, unless it is augmented by chemical reaction, it also will be of slight moment.

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5. HARDNESS.

A wall plaster is frequently called upon to resist impact or abrasion. Its hardness may be taken loosely as a measure of its ability to resist such forces. It may be argued that bumping a chair against a wall, or scratching the plaster with the corner of a desk, is a type of abuse, but the purchaser of plaster is surely entitled to receive a material of such quality that it can withstand a reasonable amount of abuse.

Resistance to abrasion may be considered almost entirely as a function of the surface finish. Any of the usual cementitious materials will harden to a satisfactory degree, provided that they are sufficiently compacted by troweling, and that nothing interferes with their hardening. That is to say, a soft dusty surface, easily scratched, is due either to insufficient troweling, or to too rapid drying. In the latter case, the mixing water is evaporated so rapidly that there is not enough left to complete the hardening reaction.

Resistance to impact is a function of the whole wall rather than of the surface only. Plaster has some elasticity. If the backing is not too rigid, the effect of a moderate blow may be simply a slight deflection of the entire wall, with no damage. If the backing will not deflect, the blow becomes a compressive stress, distributed over a localized area. The smooth troweled white finish is much stronger and more elastic than the sanded undercoats. The finish coat is deflected inward; the cohesion between the particles of the undercoat gives way to the compressive stress; these particles tend to move out of the path of the blow; this movement sets up a tendency to bulge, pushing the finish coat outward, distributed over an area surrounding the area of impact; the finish coat finally fails through the transverse stresses thus set up, and the particles of the undercoat run out of the opening.

The obvious way to overcome this type of failure is to make the undercoat stronger than the finish coat. Then, if the finish coat is not brittle, the only effect of a moderate blow would be to powder the finish coat in the area of impact. A smooth troweled white finish having this degree of softness can not be made of the usual materials without reducing its ability to resist abrasion below the satisfactory limit. The desired effect can be produced if this kind of finish is not required.

The strengths of plastering materials are regularly measured in the laboratory, but to interpret the results in such a way that they will indicate the probable behavior of the plaster on the wall requires extreme care and good judgment. The importance of the transverse strength of the finish coat under certain circumstances was illustrated above. If the construction is such that impact will cause deflection of the entire wall, the transverse strength of the undercoats may come into play. The scratch coat must have some ability to withstand shear, in order that the keys may not be broken. The compressive strength of the undercoats is likewise important under the circumstances outline above. In no case, however, is it possible to make laboratory measurements under conditions which represent the way in which the material is used. Take compressive strength, for example, in the laboratory, this is measured by loading a cylinder or cube of the material with an evenly distributed load, the sides of the specimen being free to move. On the wall the load is applied to only a small fraction of the whole area, and the sides are confined. The test specimens must be aged before they are tested, to permit the hardening to take place. The conditions to which the plaster on the wall is exposed can not be duplicated when aging laboratory specimens. If the test specimens are not made with the same proportion of mixing water as the plaster, an extremely important variable will be introduced. Any variation in the size and shape of the test piece is alone sufficient to cause an enormous difference in the measured unit strength. The degree of compactness caused by troweling on the wall undoubtedly affects the strength of the plaster, and can not be duplicated when making laboratory test specimens. The compressive strength of gypsum, as measured in the laboratory, is a very good criterion for judging whether or not the gypsum was properly manufactured. But the fact that gypsum, when so tested, will show about 10 times the strength of lime is not to be interpreted as indicating that gypsum plaster is stronger or harder than lime plaster.

6. RESISTANCE TO WATER.

The leaking of water, due usually to defective plumbing or flashing, is a kind of abuse to which plaster is frequently exposed. Damage from this source is more apt to be caused by failure of the lath than of the plaster.

If wood lath was not thoroughly saturated when the plaster was applied, it may become thoroughly saturated because of the leak. This will cause it to swell beyond its original dimensions and break the keys of the plaster.

Water standing in contact with metal lath may cause corrosion, particularly if stray electric currents are also present. This effect may be minimized by using painted or galvanized lath, and by using plaster of such a nature that the water becomes an alkaline solution. This is naturally the case with Portland cement or lime plaster, and with gypsum plaster which contains some lime. The best protection is afforded when such lath is completely embedded in such plaster.

Continued seepage of water through plaster may cause failure due to actual solution and removal of the cementitious material, or due to local expansion. Gypsum is readily soluble under these circumstances, while lime is little affected and Portland cement is improved by the water. Water coming from a leak usually wets the plaster over only a limited area. The plaster within the area tends to expand, but is confined by the dry plaster surrounding it. The result is that the wet plaster bulges out, and frequently cracks and falls off.

Where continuously wet conditions are anticipated, Portland-cement plaster should be used.

IX. DECORATIVE FEATURES.

The pleasing appearance of the walls which continuously face us has an important though seldom realized effect upon our mental attitude. A wall decorated in such a way as to be out of harmony has the same effect on sensitive eyes that continuous hammering has to sensitive ears. Proper decoration is to this extent a matter of efficiency as well as pleasure.

Whether the plaster is decorative of itself, or whether it acts merely as a base for the decorative paint or paper, this function of giving a pleasing appearance to a room is the most important one which it has to perform.

1. SMOOTH TROWELED WHITE FINISH.

This type of finish is in far more general use than any other. Its composition and application have been discussed above in Sections VII, 5 and 7. As a criticism of this type, it may be cited that it is apt to be poor acoustically, that it involves the application of a third coat, and that it is of such a nature as to show all cracks. On the other hand, its original appearance is clean and fresh. If one objects to the white color, pigment may be added. It is readily susceptible to further decoration with either paint or paper.

2. SAND-FLOAT FINISH.

Instead of applying a finish coat, the brown (or scratch) coat may be treated as follows: Bring the plaster out to a true plane surface, flush with the grounds. Watch for the time when it is sufficiently hard so that it can be troweled without danger of rubbing off, but yet is not completely hardened, and not dry. Brush the surface with water, and follow the brush immediately with a wooden float. Give a circular motion to the float. Continue wetting and rubbing until the cementitious material is removed from the surface of the plaster, and the surface presents the appearance of coarse sandpaper.

A wall finished in this way is just as sound structurally and considerably cheaper than when a white coat is applied. A little care in the selection of colored or crystalline sand or stone screenings will add materially to the appearance. The sand-float finish is, because of its roughness, somewhat better acoustically than the white finish, and is better able to conceal cracks. It can be further decorated with either paint or paper.

3. COLORED PIGMENTS.

A smooth troweled colored finish can be produced by adding certain pigments to the mixture of lime and gypsum used for the smooth troweled white finish. The commoner pigments are different iron ores for red or buff, and lampblack for gray. Chromium oxide may be used for green, cobalt glass for blue, and still more expensive materials for other colors. These pigments must be ground very fine, in order that they can be mixed uniformly in the plaster. The quantity to be used will depend upon the depth of color desired, but should not exceed 10 per cent of the weight of the cementitious material. Too much pigment, like too much of any other fine aggregate, will tend to cause excessive shrinkage and weakness.

The results obtained from the use of a colored pigment are apt to be disappointing in the hands of one not experienced with them. The cheaper colors are usually muddy. The pigment must be uniform in quality, must be proportioned exactly, and mixed with the greatest care, if a blotchy effect is to be avoided.

4. OTHER TYPES OF FINISH.

The types of finish mentioned above are those most commonly used. It is desired, however, to call the attention of architects particularly to the fact that the decorative values of plaster are capable of being developed far beyond their present state. The use of dyed wood fiber as an aggregate, as described in Bureau of Standards Technologic Paper No. 181, permits the control of color and texture. The exposed aggregate method, which has been so successfully used in stucco, might also be applied to plaster. A little study and originality on the part of architects could easily change the character of plaster from a base for decoration to a decorative medium itself.

5. PAINTING.

A coat of paint is very effective in reducing the glare of a white plaster, producing a surface which will harmonize with the overdrapes and furniture. A flat paint applied to a sand-float finish, or a stippled paint to a white finish, may be designed to give a very pleasing effect.

Either oil paints or cold-water paints may be used for this purpose, the difference being that the former will stand washing, or having water splashed on them, and that oil paints are usually lustrous although flat oil paints may be used, while cold-water paints are always flat.

Several precautions must be observed if an oil paint is to be successfully applied to plaster: Do not apply an oil paint to plaster which is in immediate contact with an exterior masonry wall. There is a strong probability that water will find its way through the wall and into the plaster and make the paint peel off. Be sure that the plaster is air-dry when it is painted. As an extra precaution, it is better to have a circulation of air behind the plaster, in order that any water trapped in it at the time of painting may find a way out. In other words, it is safer to use oil paint when the plaster is on lath rather than on masonry. A sufficient interval of time between the plastering and the painting should be permitted to elapse so that the reactions involved in the hardening of the plaster will not be stopped before they are reasonably complete. This time will vary with the kind of plaster and the weather conditions. It should never be less than three months, and probably need not be more than one year. Free lime, either as oxide or hydroxide, will destroy linseed oil, causing the paint film to become brittle. One may expect to find free lime in all green plasters, whether they be of lime, gypsum, or cement. If it is undesirable to wait long enough for this lime to be rendered inert through carbonation, a priming coat may be used. This coat is prepared by dissolving 3 pounds of zinc sulphate per gallon of water. The zinc sulphate reacts with the lime to produce compounds which have no effect on the oil.

None of these precautions need be observed in the use of cold-water paints.

6. PAPERING.

This is the most generally used type of finish for wall plaster. In fact, its use is so common that no explanatory remarks are thought necessary. It is, however, advocated that when walls are to be repapered, the old paper be entirely removed and the plaster scraped and pointed. The pointing of settlement cracks is a distinct aid in prolonging the life of the plaster, and it may be unsanitary to leave the old paper in place and cover it with new. Papering has one distinct advantage—the minor surface cracks which affect the appearance, but not the durability of the plaster, will not show through the paper.

X. TYPES AND CAUSES OF DEFECTS.

Aside from failures caused by fire or by leaks or by settlement of the building, well-made plaster should give satisfactory service indefinitely. It is only human to err, however, and, even with the best of intentions, the manufacturer, architect, contractor, or plasterer may make a mistake. The effect of a mistake probably will not be noticed before the completion of the work, and may not show for four or five years. When a failure does occur, the owner naturally wants to know the reason for it, not so much to enable him to place the blame as to guide him in making repairs.

1. STRUCTURAL CRACKS.

A large, prominent crack, extending across the surface and through the plaster, is probably a structural crack. It may start at the corner of a door or window and extend diagonally to the edge of the wall, or it may run along the corner between two walls or a wall and ceiling. The name indicates that it is due to some movement of the structural members of the building, and not to any fault in the plaster.

It might be possible to construct a building sufficiently massive and rigid so that this type of crack could not occur. A more practical expedient, however, is to let the cracks form, and then, after the building has "found itself," point them up. Unless the structure is poorly framed, the chances are that they will not reopen, and the plaster will be better than new.

2. MAP CRACKS.

This type is less prominent than a structural crack. It goes through the plaster, but it does not extend entirely across the surface. Instead, a system of cracks, running at various angles, will form more or less geometric figures over the surface. These figures are usually large (more than 6 inches across) and well defined, and the figure is repeated at different places on the surface. Hence the name.

These cracks are usually caused by a lack of uniformity in the bond between the backing and the scratch coat. Plaster is continuously expanding or contracting, following the changes in the temperature and humidity of the air. The backing is not exposed to the same conditions as the plaster, and, therefore, will probably not expand or contract to the same degree. This differential movement sets up stresses in the plaster. If the bond between it and the backing is uniform, these stresses will be evenly distributed, and will cause no trouble. But if the bond happens to be weak at any place, the scratch coat will pull loose. This will cause the stresses to be concentrated at that place, and they then become strong enough to break the plaster.

When reliance for the mechanical bond between the scratch coat and masonry wall is placed upon roughness rather than absorption, one may visualize the hardened plaster as a smooth sheet with projecting webs which fit into the depressions in the masonry. If there is little adhesion between the sheet itself and the surface with which it is in contact, the stresses set up by expansion or contraction will be concentrated along the lines where the webs join the sheet. The same effect is produced when plaster adheres better to certain parts of the surface than to other parts. In brick or tile walls, the adhesion between the plaster and the unit is sometimes different than that between the plaster and the setting mortar, and, as frequently happens, the effect may be accentuated by cleavage between the mortar and the unit. Spots of grease or laitance on concrete will have the same effect.

Map cracking is not confined to plaster on masonry. The spaces around the edges of gypsum plaster boards, or those formed by the alignment of the ends of wood lath or the lapping at the edges of sheets of metal lath, all have the same tendency—by causing an abrupt change in the thickness of the plaster, planes of weakness are set up.

Map cracking may always be taken as indicating that the bond between the plaster and the backing is not uniform. The remedy is obvious.

3. SHRINKAGE CRACKS.

Shrinkage cracks resemble map cracks, except that both the cracks themselves and the areas which they surround are much smaller. They do not go clear through the plaster, being confined usually to the finish coat.

If the finish coat is sanded, shrinkage cracks indicate that the plaster was too rich, that it was permitted to dry too quickly, or that it was not trowelled enough. Shrinkage cracks in a white finish indicate that it was trowelled too soon.

Shrinkage cracks have little effect on any of the properties of plaster except its appearance. If this gets to be too bad, another coat of finishing plaster, or wall paper may be used to cover up the cracks. If a new white coat is to be applied, the old white coat must be removed or roughened, by hacking, to provide a mechanical bond for the new coat. Do not try to use a gloss paint. Each little area surrounded by shrinkage cracks is slightly concave, or turned up at the edges, so that a gloss paint will make the cracks stand out in high relief.

4. POPPING.

Lime "burned" during hydration, certain compounds of lime with silica or iron, iron pyrites, and many similar substances have one property in common: They are not acted upon very readily by water, but when exposed for a long time they will hydrate, and this hydration is accompanied by an enormous expansion. Whenever particles of such materials find their way into plaster, they remain apparently inert during the mixing application, and hardening. Three months or a year later, they will begin to hydrate. The expansive force is so great as to push the particle and everything in front of it out of the wall, leaving a little conical hole, called a "pop." In extreme cases, these pops may be so large and numerous as to be quite disfiguring. If hydrated lime was used, the responsibility for this type of failure rests with the manufacturer; if quicklime was used, it rests with the contractor who did the slaking; if no lime was used, the quality of the sand should be investigated.

The size of a pop depends upon the size of the particle causing it. If the particle is very small, the pop may be so small that it will not be noticeable. Freedom from noticeable pops will be assured if the lime contains no particles which would be retained on a No. 50 sieve, or if particles coarser than this are of such a nature that they will not cause popping.

5. EXPANSION.

It was noted above that map cracking is caused by a differential movement of the plaster and the backing. This movement is just as apt to be expansion as contraction. The effect is quite different, however. If the bond between the scratch coat and the backing has been broken, over a small area, and the plaster is expanding, due to rising temperature or increasing humidity, compressive stresses will be concentrated in the plaster over this area. The first effect will be to make the plaster bulge out from the wall. This is indicated by the hollow sound given out when the plaster is struck at this point. Plaster is somewhat elastic, and the movement is usually quite slow, so that considerable bulging can take place before failure occurs. If, at this time, the atmospheric conditions change and the plaster begins to contract, it may go back to its original condition with no apparent damage. If expansion continues, however, it will eventually break the plaster. The break will not be a clean crack such as is caused by contraction, but will be more in the nature of a shattering.

The usual cause of failures due to expansion and the remedies therefor, have been discussed under map cracking. There is one rather rare circumstance which could cause expansion but not contraction: When water is trapped in a plaster containing considerable quantities of magnesium oxide, the expansion due to the hydration of the magnesia will be very slow but very great. This apparently does not occur when the magnesia has a chance to carbonate rather than hydrate.

6. SEPARATION OF COATS.

In the above sections (X, 2 and X, 5) it was assumed that in the shrinkage and expansion the plaster moved as a whole; that the bond between the scratch coat and the backing is the important feature. But the coats are apt to move with respect to each other as well as with respect to the backing. This is aggravated by the fact that the coats are of different compositions and subjected to different conditions of exposure. The same rules apply here as in the previous case; the bond between the different coats must be not only good, but uniform, in order that the stresses may be distributed rather than concentrated. The white coat is most subject to these movements, because of both its composition and its exposure. Fortunately, therefore, its strength and its elasticity make it best able to withstand them.

7. SOFTNESS.

It is necessary that plaster shall have a certain degree of hardness, in order to withstand usual abuse, even though this hardness is detrimental to its acoustical properties. The finish coat must be hard enough so that it will not rub off on the clothes. It should be possible to drive a nail through the finish coat without having a large amount of the under coats run out through the hole.

Such troubles are usually due to the use of too little cementitious material, or to causes which have prevented it from hardening properly.

8. BLOTCHES AND EFFLORESCENCE.

Sometimes areas of considerable size have the appearance of being wet. They dry out after awhile, but may come back again intermittently over a long period of time. These blotches are caused by certain salts in the plaster, which are soluble and hygroscopic. As the mixing water evaporates, these salts are brought to the surface and deposited. Their hygroscopic property causes them to absorb water from the air, thus keeping the plaster damp. Calcium chloride is typical of this kind of salt. It is readily formed by interaction between lime and common salt. This is one reason why sea water or beach sand should not be used for plastering.

If the salt is soluble but not hygroscopic, it will be deposited on the surface of the plaster as a white crystalline material which can easily be rubbed off. These crystals may grow to a considerable length. They may reappear if they are rubbed off before all of the salt has been brought to the surface. They are usually magnesium sulphate, formed possibly by interaction between the gypsum and the magnesia in the finishing lime.

Sometimes a white finish is mottled gray and white. The areas of each color are so small that they are distinguished only on close inspection. This is due to the use of lime and gypsum of slightly different colors, which were not mixed as thoroughly as they might have been. These spots are permanent, and in no way affect the quality of the plaster.

Sometimes discoloration, due to collection of dust, outlines the units of the backing to which the plaster is applied. A possible explanation for this is as follows: Plaster is usually cooler than the air in contact with it. Frequently it is so much cooler that it is below the dew point, and moisture is condensed out of the air and deposited on the plaster. This moisture is drawn by suction from the surface into the interior of the plaster. Eventually the plaster becomes saturated and some moisture remains on the surface. This collects dust from the air. Regarding the plaster as a reservoir for the absorption of water, it will be seen that the space between the backing units will absorb more water than the space in front of such units, because there is more plaster in the former space, and the plaster absorbs more water than the unit. Therefore the space in front of the unit will become saturated more quickly, and then discolored. If the discoloration occurs over the joints instead of over the units, it means simply that the unit is more absorptive than the plaster. This type of defect is most noticeable with wood lath and clay tile. It does not occur with metal lath. It can be remedied by painting the plaster.

9. PEELING OF PAINT.

The peeling or blistering of paint is almost always due to the presence of water in the plaster. It is quite unusual to paint plaster before it is sufficiently dry, so that this phenomenon may be taken to mean that water from some source is getting into the plaster. Look for leaks in the plumbing or flashings, or for the possibility of water seeping through from the other side of the wall. (This is another reason why furring is recommended.) If the floor is frequently mopped with water, an impervious baseboard is necessary to prevent the water from being absorbed by the capillary action of the plaster.

The action of free lime in the plaster may be identified by what looks like shrinkage cracks in the paint. The areas inclosed by the cracks are very small. The paint film in each area is brittle and lacking in lustre. This should have been prevented by the use of a priming coat.

10. WRINKLING OF PAPER.

Paper expands when it gets wet. The wrinkling of wall paper may, therefore, be taken to indicate that water is condensing out of the air on to the surface of the paper. The possible causes of such condensation have been discussed in Section II. This is not serious, for the paper usually shrinks back to its original size when it dries out.

Of course, the water may come from a leak, but this can be distinguished by the fact that the wrinkling is localized.

XI. THE KIND OF MATERIALS TO SELECT.

The choice of materials usually represents a compromise between what the purchaser wants and what he can afford to buy—between the quality and the cost. Quality may be subdivided into the decorative and the structural features which it is desired that the finished plaster shall have. The cost item should include the cost of materials and labor, the loss in the time of occupancy of the building, and the probable cost of maintenance, depreciation, and repairs.

The structural design of a building is rightly based upon engineering principles rather than upon its suitability for plastering. In many cases, therefore, the type of backing to which the plaster is to be applied is selected by the architect or engineer, and the plasterer has no choice in the matter. Since it is recommended that all exterior walls be furred, the above note applies only to bearing partitions and to ceilings. In all other cases, and also in suspended ceilings, the purchaser is free to choose the type of backing, on the basis of its suitability to receive plaster. In all cases, he is free to choose the materials of which the plaster is to be made.

1. CLASSIFICATION OF PLASTERING.

In order to guide the purchaser in the selection of proper materials, it has been found expedient to classify plastering into four groups. The classification is based on the ratio of quality to cost, in the hope that the purchaser will find his requirements reasonably well met by one of the classes. While the classes of plastering are most conveniently described by the classes of buildings in which they are generally used, care should be taken to avoid confusion. The purchaser is entirely at liberty to buy a better grade of plastering than would generally be used in the kind of building he is erecting. He is also at liberty to use a poorer grade, provided he knows in what respects it is poorer, and takes the necessary risks. It may also be found economical in some cases to use a better class of lath and plaster in the more prominent parts of a building.

Class A plastering is the best which can be had with the usual materials, at any cost. Quality is of paramount importance.

Cost is a very minor consideration. Such plaster is used in public buildings of the monumental type, where appearance and durability are given prime emphasis.

Class B plastering is that adapted for use in buildings which, while of excellent construction, must nevertheless earn a reasonable return on the investment. Such buildings are first-class office buildings, apartment houses, factories, etc.

Class C plastering is selected on the basis of economy of first cost. It is expected that the occupancy of the building will keep down the maintenance cost. This is the class of plastering most generally used, being adapted to small office and apartment buildings, factories, and the better grade of dwellings.

Class D plastering is the minimum quality which should be permitted under any circumstances. It represents the case where quality has been sacrificed to cheapness to the limit of satisfactory service.

2. EXTERIOR WALLS.

Where class A plastering is to be used, the walls will probably be of masonry. On such walls, furring must be used. The purchaser has the option between split clay or gypsum furring tile, or metallic lath on metal furring strips. If metallic lath is used, it must be heavy weight expanded, or wire, with the furring strips not more than 16 inches on centers. The wire lath has some advantage over the other types in that the wire is more apt to be completely embedded in the plaster.

The plaster may either be lime or gypsum, but when on lath shall consist of three coats and be seven-eighths inch thick. When on furring tile, it shall consist of two coats, and be not thicker than five-eighths inch. If gypsum furring tile is used, the plaster should also be of gypsum, to insure a good bond. On the other backings, lime has some advantages because of its greater effectiveness in preventing corrosion and because its slower hardening gives the plasterer more time to work it to a true and plane surface.

The same remarks apply to class B plastering, except that medium weight expanded metal lath may be used.

Class C plastering may frequently be used in buildings, the exterior walls of which are not masonry. When they are of masonry, the above remarks apply, except that lightweight metal lath and wood furring strips may be used. When the walls are of frame construction, the studs which support the lath shall be spaced not more than 16 inches on centers. Light weight metal lath, No. 1 wood lath, or three-eighths inch gypsum plaster board may be used. The plaster board and metal lath are incombustible. Metal lath will act more in the nature of a reinforcement, tending to prevent the plaster from cracking.

Either lime or gypsum plaster may be used, but it shall be three-coat work, seven-eighths inch thick. Gypsum has certain advantages, in that it requires less time for the completion of the building, and it affords a little better fire protection for the wooden studs or lath.

For class D plastering furring may be omitted. Plaster applied directly on masonry shall consist of two coats of plaster and be not more than five-eighths inch thick. Portland cement plaster is recommended when the masonry is below grade. Gypsum plaster must not be applied directly to a concrete wall.

When furring is used, or when the wall is of frame construction, the requirements for class C plastering apply, except that No. 2 wood lath or one-fourth-inch plaster board may be used.

3. PARTITION WALLS.

A partition wall, if designed to carry a load, will be constructed of materials which are selected without reference to the plastering. The problem here is to apply plaster to a given wall. Nonbearing partitions may and should be designed with particular reference to their ability to receive plaster. However, bearing partitions are frequently built of wood studs instead of masonry, and it is frequently desirable to build nonbearing partitions of masonry instead of studs. So the two cases may be discussed together.

Nonbearing partitions are usually built of clay or gypsum tile or wood or metal studs.

For class A plastering, which is designed to be used in buildings which are essentially fireproof, it would obviously be out of harmony with the general scheme to erect a wood stud partition. Either clay or gypsum tile should be specified unless a solid metal lath—metal stud partition—is to be used. The gypsum tile has some advantages over the clay tile: It is lighter, causing a less floor load; it is better acoustically; and nails can be driven into it.

The great advantage of the solid metal-lath partition is the saving of space. This type is only 2 inches thick, whereas a good tile partition will have an over-all thickness of 5 or 6 inches, including the plaster. While this type of partition can be used for class A plastering, its use calls for the exercise of good judgment.

For a gypsum tile partition gypsum plaster is preferred, because it is customary to apply the plaster without wetting the tile, and the great suction may prevent the proper spreading of a lime plaster. For clay tile either lime or gypsum may be used. In either case the plaster should consist of two coats and not be over five-eighths inch thick. For glazed clay tile three coats are recommended.

The solid metal-lath partition requires, for class A plastering, the use of heavyweight wire or expanded metal lath and Portland cement or gypsum plaster. Maximum strength of both lath and plaster are necessary to develop the required rigidity. The studs shall be spaced 16 inches on centers. The plaster shall be applied in three coats on each side of the lath, making a total thickness of five-eighths-inch over each face of the stud.

For class B plastering the same remarks apply except that a solid partition may be built of medium weight metal lath or three-eighths-inch gypsum plaster board.

Class C plastering is frequently used on a wood-stud partition. The studs shall be spaced 16 inches on centers. Lightweight expanded metal lath, No. 1 wood lath, or three-eighths-inch gypsum plaster board may be used. Either lime or gypsum plaster may be used, but shall consist of three coats, seven-eighths inch thick. Gypsum plaster shall be used if the backing is gypsum plaster board.

When the partition is not of wood studs, the requirements for class B plastering apply, except that lightweight expanded metal lath or one-fourth-inch gypsum plaster board may be used for solid partitions.

The requirements are the same for class D plastering as for class C, except that No. 2 wood lath or one-fourth-inch gypsum plaster board may be used on wood stud-partitions.

4. CEILINGS.

The requirements for plaster on ceilings are more severe than for plaster on walls. The difficulties of application are much greater. The plaster is continuously under the stress of gravitation and is, therefore, more susceptible to the destructive action of vibration. The fire-resistive ability of a ceiling is much more important than that of a wall.

Class A plastering will be called for only when the ceiling is of masonry or is suspended.

If the masonry ceiling is of gypsum tile, gypsum plaster shall be used. If the ceiling is of clay tile, either lime or gypsum may be used. In either of these cases the first coat should be sanded and should be as thin as possible and still produce a true and even surface. Any unnecessary increase in the thickness of plaster increases its weight and, therefore, throws more strain on the bond between it and the masonry.

If the ceiling is of concrete, apply only one coat of lime plaster gauged with gypsum, and without sand. This coat must be made as thin as possible. If a plane surface is desired, this should be obtained by using smooth forms for the concrete, and not by attempting to fill uneven places in the concrete with plaster.

Suspended ceilings shall be rigidly attached to the masonry at intervals not to exceed 12 inches in either direction. Sheet metal, heavy-weight expanded metal, or wire lath may be used. Gypsum plaster is recommended. The weakness of an ungauged lime scratch coat is such that there is imminent danger of shearing the keys, both during the application of the finish coat and after the plaster has hardened.

Class B plastering should be the same as class A on ceilings; the requirements are so severe that none but the best will give the service expected.

Class C plastering is frequently applied under wooden floor joists. In this position, the fire resistance of the lath and plaster is of paramount importance. If the joists are more than 16 inches apart, a suspended ceiling may be erected, or furring strips, 12 inches on centers, may be attached to the joists at right angles, in order that the lath may be supported at sufficiently frequent intervals in both directions. Narrow furring strips shall be inserted between the lath and the joist whenever the face of the joist is more than 2 inches wide.

Medium-weight expanded metal lath, and gypsum plaster shall be used, in order to get maximum fire resistance at reasonable cost. The plaster shall be three-coat work, seven-eighths inch thick.

When class C plastering is to be applied to masonry, class A requirements hold. For suspended ceilings, class A requirements also apply, except that medium weight expanded metal lath may be used.

Class D plastering may differ from class C in the following particulars: The points of support for lath may be 16 inches apart. Medium weight expanded metal lath or three-eighths inch gypsum

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plaster board may be used, either when the lath is attached to the joists or when it is suspended. Either lime or gypsum plaster is permissible, except that gypsum plaster must be used on gypsum plaster board or gypsum tile.

5. PORTLAND CEMENT PLASTERS.

It will be noted that in the above discussion only lime and gypsum plasters have been considered. These two materials represent possibly 90 per cent of the business. Portland cement makes a plaster which has certain marked advantages over lime or gypsum, in its ability to withstand abuse. It is at least equal to gypsum in its fire resistance, and superior to it in resisting the action of water.

The notorious lack of plasticity of Portland cement makes its use as a plaster extremely difficult and, therefore, costly. But undoubtedly the chief failing which hinders its use is its color. Plaster is, in the vast majority of cases, primarily a decorative material.

When Portland cement plaster is used at all, it must be used in the scratch coat. The application of a strong Portland cement finish coat over a weak lime or gypsum undercoat is sure to result in failure.

6. MIXED CEMENTITIOUS MATERIALS.

It is not at all unusual to mix two cementitious materials in an attempt to produce a plaster having the good points of both.

Lime and gypsum mixtures are the most common. The neat materials are customarily used for smooth-trowelled white finish, and even gypsum intended for the under coats usually contains some hydrated lime to improve its plasticity. Lime acts as a retarder for gypsum, so that if much lime is required (as for a high degree of plasticity) it may be necessary to use some accelerator. The new "plastic gypsum" (U. S. patent No. 1392574) is designed to do away with this use of lime.

Lime and Portland cement may be mixed in any proportions. A little lime added to cement will improve its plasticity and sand-carrying capacity, and will have no deleterious effect except that the mixture will set more slowly. A little cement added to lime will increase the hardness and fire resistance, and will have no deleterious effect except on the color. About 15 per cent of one to 85 per cent of the other, by volume, is a good proportion to use.

The lime may be mixed as either dry hydrate or wet putty, the volume equivalent being the same.

Keene's cement is sometimes mixed with lime, to produce a plaster having the plasticity of lime and the hardness of gypsum. The advantage of Keene's cement over gypsum is that mixtures of the former with lime can be soaked for four or five hours before use. This property permits the mixing of larger batches, and the soaking assists in developing the plasticity of the lime.

Portland cement shall not be mixed with gypsum or Keene's cement. There is a possibility of some kind of deleterious reaction between Portland cement and calcium sulphate. The nature of this reaction is not definitely known, but experience clearly indicates that the two materials should not be mixed.

7. SPECIAL REQUIREMENTS.

Where special fire resistance is required, as in soffits over stairways, or walls of elevator shafts in "fireproof" buildings, gypsum plaster or Portland cement plaster, containing not more than 15 per cent of lime, will give the best results.

Portland cement plaster is the best when the chief requirement is the ability to resist moisture and impact, such as basement walls or warehouses.

From the standpoint of acoustics, gypsum wood fiber plaster is the best, especially if the surface is treated in such a way as to expose the fiber. This will reduce the echo. To reduce the transmission of sound, the construction should be thick, heavy, and rigid without being resonant.

8. CONTRACTS.

When letting a plastering contract, due consideration should always be given to the selection of materials best adapted to the particular work. The public is cautioned to remember that the value received is usually dependent upon the price paid. Efforts to drive too close a bargain are only temptations to use inferior materials and to "skimp the job." Awarding contracts blindly to the lowest bidder is an important cause of the excessive maintenance cost of plastering in the United States to-day.

XII. REFERENCE.

In the body of this report, only a few quotations have been made from the great mass of literature available. Most of the members of the conference have published their findings on certain phases of the subject. For those who would study further the reasons back of the conclusions contained in this report the most up-to-date information can be obtained by direct correspondence with the appropriate members of the Bureau of Standards Plastering Conference, listed on page 4.

WASHINGTON, August 20, 1923.