CERAMIC TILE INSTITUTE OF AMERICA, INC.
12061 Jefferson Blvd., Culver City, CA 90230-6219

CTI FIELD REPORT 73-2-7 (R-85)

SUBJECT: Portland Cement, Aggregates, Plasticizer and Water

1. INTRODUCTION

1.1 Early in 1973 Ceramic Tile Institute worked with engineers and obtained detailed information especially important to the items covered in this Field Report:

1.2 "There are internal stresses caused by the tile and material which the tile industry uses, especially our mortars."

1.3 "We want to use materials to install our ceramic tile which,
A. Are substantial in permanently bonding the tile.
B. Are used in such a way that the internal forces are held to a minimum.

1.4 There are a number of items which will keep the internal stresses to a minimum. The properties and proportions of the sand, Portland cement and lime, plus water, will keep the internal stresses to a minimum if they are correct. Each of these items, their qualities and quantities to be used, will be discussed under their following headings.

2. PORTLAND CEMENT

2.1 The basic ingredient in most mortar mixes is Portland cement, which is the same material used in concrete.

2.2 The name “portland” is not a brand name and is not derived from the name of a city. It was given to the product in 1824 by Joseph Aspdin, an English stonemason; because he thought the concrete made with it resembled the stone quarried from the Isle of Portland in England.

2.3 Portland cement is not used by itself for construction but is mixed with other ingredients. Mixing it with water creates a paste that will bind it together with such materials as sand and gravel, thus forming concrete. The paste grows harder as it ages and in time becomes stronger than the rocks or other aggregates which have been mixed with it.

2.4 The Portland cement mortar used in setting beds by tile setters is of the same origin as this concrete, but it does not contain the rocks and other large sized aggregates that concrete does. This makes the measurement of the cement content of the mortar very important.

2.5 Except in unusual situations, and unless these situations are specified by the architect. Type I or Type II portland cement conforming to ASTM C150 is to be used for tile setting beds.

2.6 Ceramic Tile Institute recommends one part of Portland cement to three parts of sand for the scratch

2.7 Ceramic Tile Institute recommends one part of Portland, one part of lime and six parts of sand for wall mortar.

2.8 Strangely enough, the only way the advantages and virtues of Portland cement can be lost is in going to extremes in using it. Not enough cement will make weak mortar, but too much cement causes excessive shrinkage and builds up the stresses we are trying to minimize.

2.9 Note the proportions stated in paragraphs 2.6 and 2.7.
Portland cement and lime are both cementitious materials. In commercially graded sand, voids amount to closely one-third the volume of the loose sand. Thus the accepted rule: 1 volume of cementitious materials to 3 volumes of sand. Additional information will be given on this where sand is discussed.

3. AGGREGATES
3.1 Sand.

A. Sand for mortar should consist of hard, strong, durable uncoated mineral or rock particles free from mica, organic matter, saline, alkaline, or other deleterious substances.

B. Sand shall be kept free of organic or deleterious matter that may produce stains in the joints, affect the setting time of the cement or cause excessive shrinkage. Clays, in the sand deposits, are undesirable and cause excessive shrinkage.

C. Grading. Mortar sand should not be as coarse as ordinary concrete sand and should be properly graded from coarse to fine within the following limits: (natural, not manufactured).

Sieve Size	**ASTM – Revised 1961 Percent Passing**
No. 4	100
No. 8	95 to 100
No. 16	70 to 100
No. 30	40 to 75
No. 50	10 to 35
No. 100	2 to 15

D. Fineness Modulus. A fineness modulus of mortar sand between the approximate limits of 2.25 and 2.75 is recommended. (Fineness modulus is the summation of the percentages of dry sand retained on standard sieves numbers 4, 8, 16, 30, 50 and 100 divided by 100).

E. Voids in sand may be defined as the empty spaces among the grains of sand. If a metal cylinder is filled level full of sand, an amount of water may be poured into it without overflowing, since the water simply fills up the air spaces. When the sand has settled down, and is saturated without free water standing on top, the volume of water required to saturate the sand would represent the volume of voids in the sand. In commercially graded sand, this void volume is closely 1/3 the volume of loose sand. Thus the accepted rule: 1 volume of cementitious materials to 3 volumes of sand. Actually graded sand has 34 percent voids.
In any loose or granular material the largest percentage of voids occurs with particles all of the same size and the smallest percentage occur with particles of such different sizes that the voids of each size are filled with the largest particles which will fill them.

F. To prove its value some compressive tests on 2x2 cubes of mortar, made with graded sand, have been conducted by the Ceramic Tile Institute. More comprehensive studies are available in masonry and plastering manuals. These studies show shrinkage increases and both compressive and tensile strengths decline when there is a predominance of either fine or coarse particles present.
When there is a blend of particles of the proper sizes, which supplies the prescribed grading, the compressive and tensile strengths are dramatically increased.
(a) An additional one third in PSI is the added strength in compressive tests.
(b) An additional two thirds in PSI is the added strength in tensile tests.

G. Requirements. Tile reference specifications require sand to meet ASTM Specifications C144, which require a definite grading from fine to coarse and limit the fine sand to not less than 2% nor more than 15% passing the No. 100 sieve. The reason for this is that a mortar sand must contain a percentage of fine particles which act as ball bearings in a mortar, and which aid in producing a more workable and compact mass.

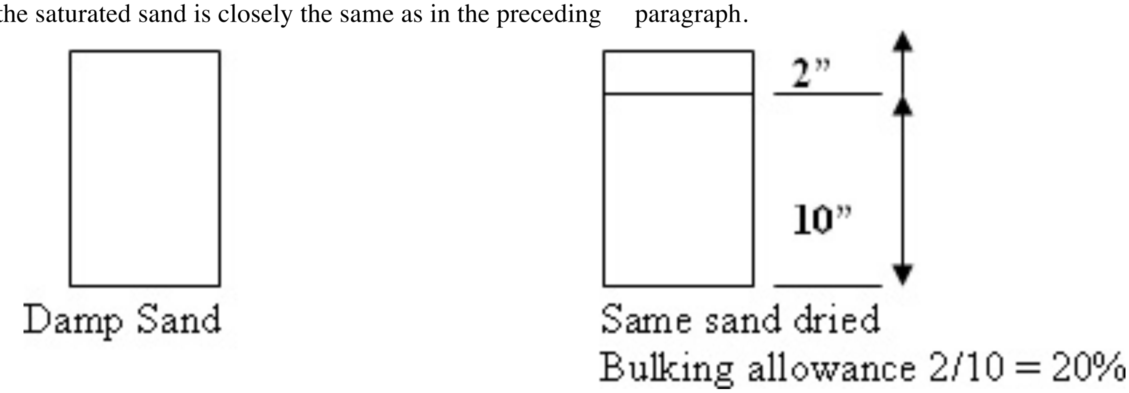
In washed sand, these fines are washed out and, with the same volumes of mix, washed sand makes a harsher mortar and usually requires more lime to provide the required plasticity and water retention.

Mortar proportions are invariably set for the cement and the sand with the variable applying to a minimum and maximum amount of lime. Since graded sand, when dry, contains about 1/3 voids, the sum of cementitious materials, cement plus lime, must be about 1/3 of the volume of the sand.

H. Bulking. Where the volume of sand is specified on dry, loose measurement, and the sand on the job is damp, it is necessary to allow for bulking.

A simple method of determining this is to carefully fill a 6"xl2" cylinder level full of the damp sand, without tamping, then carefully dry out this sand, after which, place it back in the cylinder. The distance the surface of the dry sand is below the top of the cylinder, divided by the depth of the sand will give the percentage of damp sand to be added to obtain the specified volume. If this distance is, say 2", then (2 divided by 10) 20% bulking must be added to the sand volume.

Another method is to pour enough water into a sand-filled cylinder until the sand is completely saturated and settled and the cylinder is level full of water. The distance from the top of the cylinder to the top of the saturated sand is closely the same as in the preceding paragraph.



3.2 Vermiculite

A. Vermiculite is a lightweight mineral aggregate formed by subjecting the mineral vermiculite, which is a type of mica, to high temperatures. The furnace heat expands the plate-like particles in much the same way as an accordion is expanded by drawing apart the leaves of the bellows. The final product weighs only eight pounds per cubic foot.

B. More study is needed on vermiculite for usage with tile. Where experimental work has been done it shows it requires more water than sand.

C. Mortars containing vermiculite have shrunk more than corresponding mortars containing perlite and the perlite has shrunk more than corresponding mortars containing graded sand.

3.3 Perlite

A. Perlite is another lightweight cellular aggregate. It is formed from volcanic glass that has been ground to a fine sand size and then passed through a high temperature. This tends to bloat or expand the particles by softening them sufficiently to permit the entrapped gases to swell the perlite several times its natural size.

B. This lightweight aggregate has been successfully used by tilesetters in mortar mixes to partially or wholly replace the sand.

A low-alkali portland cement should be used with perlite.

C. Where experimental work has been done it shows that the shrinkage of mortar containing perlite was closest to that of mortar containing sand. With both sand and perlite, the most shrinkage occurred during the first seven days.

4. PLASTICISERS

4.1 A construction dictionary gives the following definition for plasticiser: "A material that increases plasticity of a cement paste, mortar or concrete mixture".

4.2 There are a number of plasticisers on the market but the tile industry has relied on lime to provide the necessary plasticity in mortar and so that is the only material that will be included in this report.

4.3 Lime

A. Lime is a cementing agent that provides water retention and plasticity in mortar. The effect of lime crystallization is an increase in the bond strength. It also gives greater flexure and shear strength to the mortar.

B. The crystallization of lime not only increases the bond strength, but, over a period of many years, heals fine cracks caused by shrinkage or other causes.

C. Dry mortar with lime content has considerable suction when brought in contact with wet mortar; therefore, lime is usually left out of scratch coats.

D. ANSI A 108.1 recommends a mortar mix of 1-1-5 to 1-1-7 (cement-lime-sand). Because of the plastic properties of various limes and the different grades of sand, these formulas sometimes have to be varied to obtain a proper working plasticity. The lime content should be increased or decreased, rather than the cement. This will keep the shrinkage of the mortar and the internal stresses to a minimum.

5. WATER

"Water that is suitable for drinking" is not necessarily the best for mixing mortar. If it contains sugar or citrates, the water is suitable for drinking, but not for mixing mortar. In reverse, not all water unsuited for drinking is unsatisfactory for use in mortar. If the water used to mix the mortar comes right out of a supply that is intended for domestic use, the tile setter may be reasonably sure that it is all right to use. However, because water that has been standing in a barrel or other container on the job may have been used to wash equipment, it should not be used for mixing mortar.

6. SUMMARY

6.1 Shrinkage and internal stresses of mortar can be kept to a minimum by the following:

A. Use Type I or II Portland cement, conforming to ASTM C150, in its proper proportion.

B. Use clean graded sand, conforming to ASTM C144, in its proper proportion.

C. Use lime, conforming to ASTM C206-49 or ASTM C207-49, Type S, in its proper proportion.

D. Use clear and potable water, taken from a supply for domestic use.