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REPORT

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A Dissertation on Mortars and allied Substances.

by F.W.Anderson, 1977.

Introduction.

The mixture of sand and cement known as mortar has been used for many centuries to bind together the building material, such as stone and brick, into a strong and stable unit, to form a hard level flooring, as a base in which to set tiles and tesserae, as a facing for rubble walls, as the priming for a coat of plaster and as the basis, with the addition of a coarse aggregate of stone, for concrete.

Such are the variations possible that it is not easy to produce a practical classification of this material. The mixture has , however, only two main components i.e. sand and cement and the proportions in which they are mixed are fairly rigidly controlled according to the use to which the final product is put. When used as a binding materialthe mixture when set needs to be similar in strength to the stone or brick concerned. If the proportion of sand is too high the binding properties of the mortar will be poor, too little sand and the mortar will tend to shrink and may damage the stone work. A practical necessity is that the mixture must spread evenly and must be free of pebbles larger in diameter than the space to be filled. This is particularly important if the material is to be applied to a vertical surface by trowel', but of little consequence in concrete or flooring which can be poured or puddled into place. In general pebbles of more than 5mm diameter need to be excluded. The first essential for a good mix is that the sand should be screened and graded so that on the one hand too large grains are eliminated and on the other that the spaces between the larger grains are reasonably well filled. Also the sand must be clean so that the pore space is not filled with clay or silt. A small amount of clay is often added in order to slow down the setting of the mortar but this can make it difficult to get a uniformly even mix. A well compacted sand has a porosity of between 40% and 60% , thus it is not possible to produce a cement containing more than say 50% of sand by volume. Theoretically it should be possible to fill completely the pore space with cement but this is rarely achieved even in nature. The nearest approach is where a sandstone has a silica cement as in Ganister, or has been recrystallised as in a Quartzite. In any case some of the pore space must remain unfilled so that air containing CO_2 can reach all the CaO and convert it into the carbonate.

From Roman times onwards it has been customary to use three parts of sand to one of cement for a mortar mix or, in the case of a fine sand, two parts of sand to one of cement (Vitruvius). A well-graded sand is one in which the sand grains can be closely packed, thus reducing the voids and saving cement. In general sand in which the individual grains range from 0·15 mm to 0·45mm diameter has been most commonly used, the bulk of which is between 0·25mm 0·35mm diameter.

Definitions.

One of the difficulties encountered in this series of mortar analyses is that even the most authoratative sources have been reluctant to define what is meant by the term mortar. Though there are some exceptions , the practical builder should have no such problems. If the various types of sand-cement mix are classified according to the use to which they are put there are obvious limiting factors. In the following account the mixes are defined as,-

M. Mortar. A sand-cement mix generally in the proportion of three or four parts of sand to one part of cement used to bind together ashlar blocks, bricks, tiles or close-fitting rubble. The mix must be strong enough to bind but not strong enough to crack or damage the materials to be bound. A limiting factor is the size of the joint, obviously no pebbles can be included larger in diameter than the joint to be filled. Moreover, pebbles make it difficult to trowel the mortar. Chalk slurry (Cob), clay, bitumen etc.which have been used as binders or lubricants should not be classed as mortars.

C. Concrete. The composition of this mix is extremely variable. It generally consists of a mortar (the fine fraction) to which has been added pebbles and/or angular fragments of rock (the coarse fraction). Some types of rubble should be included in the term concrete since the mortar is not necessarily applied in the same way as in ashlar and the size limitations are less significant. The essential requirement is that the fine fraction shall adequately fill the voids in the coarse fraction.

In general concrete is poured into place and even in rubble building the trowelling technique is different from that used with ashlar or brick.

R. Rendering and screeding. This mix, used for flooring, facing walls, as a bed for tesserae and as an under plaster is also variable in composition depending on the use for which it is designed. In general it contains less sand than a mortar. The sand grade is largely determined by the method of application. If applied by trowel or float pebbles of any size must be excluded, on the other hand if the mix is projected against a wall as in rough-casting, the proportion of pebbles can be quite high.

It is evident that at times normal mortars have been used for rendering.

P. Plaster and stucco. The sand content in plaster is usually low and may even be absent. A fine-grained sand is normally used with cement and a proportion of crushed chalk or limestone and clay.

Though gypsum plasters were introduced into England in the 13th.Century they must have always been expensive to produce. No examples have been seen from any of the sites so far examined.

Before embarking on a study of mortars it is necessary to examine in some detail the two major constituents i.e. sand and cement.

Sand. Sand is an aggregate of mineral grains with diameters ranging from 0·06mm diam. to 1·27mm diam. Smaller grains 0·01 to 0·06mm diam. are classified as Silt, and if less than 0·01mm diam. as Clay. Larger fragmeents ranging from 1·27mm diam to 10mm diam are classified as Gravel and if larger than 10mm diam , as Pebbles. There is no universally accepted standard of grading for sand. That adopted here is a compromise,-

Pebbles................	greater than 10 mm diam.		
Gravel..................	1·27mm	to	10mm. diam.
Very coarse sand,,,,,,,,,	0·64mm	to	1·27mm diam.
Coarse sand............	0·31mm	to	0·64mm diam.
Medium sand............	0·21mm	to	0·31mm diam.
Fine sand..............	0·13mm	to	0·21mm diam.
Super-fine sand........	0·06mm	to	0·13mm diam.
Silt...................	0·01mm	to	0·06mm diam.
Clay...................	less than 0·01mm diam.		

Natural sands show some degree of sorting. For example river and beach sands range from 0·16mm to 0·57mm diam. with a mode about 0·33mm diam.

The constituent mineral is generally quartz though there is often a small percentage of other minerals (usually not more than 10%). Some beach 'sands', however, may consist largely of Calcium carbonate in the form of shell debris. No such shell 'sands' have been encountered in the present study.

The physical and chemical properties of quartz sand are of vital importance in the building industry. The material is virtually insoluble and therefore not affected by normal weathering processes. It is almost incompressible and therefore will sustain very large compressive stresses. It has no tensile strength hence the need for some binding material such as cement to hold it together. Sand has a theoretical porosity of 48% assuming the grains to be all spherical and of the same diameter i.e. 100 cc of sand should accept 48cc of water without any increase in volume. The porosity of sand is defined as the ~~total pore space~~ percentage of pore space in the total volume. For coarse sand the porosity is 39-41%, for medium sand 41-48% and for fine sand 44-49%. This, however, is the total not the effective pore space. Total pore space includes all intetices or voids whether connected or not and so is always greater than the effective pore space. If the sand is graded some of the pore space will be partly filled by the smaller grains and the porosity reduced.

Tests on a medium sand, mode 0·28mm diam., graded 20% fine, 40% medium, 40% coarse accepted 42% of water without increase in volume i.e. the porosity was only 6% less than that calculated. Testing a 3-1 dry mix i.e. 75cc sand with 25cc cement, the sand would contain 39cc voids, which accepted 26cc water, thus 39cc sand +25cc lime+ 26cc water = 90cc leaving 10cc voids in the set mortar.

If all parts of the mixture are to be reached by air containing Carbon dioxide the the mix must have some permeability. This is not the same thing as porosity. Permeability is a function of 'useful porosity' and is dependent on the packing of the sand grains and therefore on their shape, size and grading.

In the following study sands are classified as fine if the grading shows a predominating percentage of grains of less than 0·21mm diam., as medium if grains between 0·21 and 0·31 mm diam. predominate, and coarse if grains larger than 0·31mm diam, predominate.

Cement. Calcium carbonate is burnt to form quicklime and slaked with water i.e. hydrated. Pure Calcium carbonate such as white chalk and oolitic limestone produce a non-hydraulic or fat lime. If Aluminium silicates such as those present in clay, gray chalk or argillaceous limestone are added the lime will be hydraulic or semi-hydraulic. A non-hydraulic lime is slowly converted to Calcium carbonate by the action of Carbon dioxide in the atmosphere. Hydraulic limes will set under water by the formation of calc-silicates and calc-aluminates. Thus additives such as burnt shale, burnt clay, powdered tile, brick or pottery, slags etc.have sometimes been added to produce a harder cement and/or one which will set under water. Volcanic material such as pozzolana (or trass) was used by the Romans but in post-Roman times does not appear to have been used again until the 16th.Century. Thus the majority of mortars now being investigated can be assumed to have been made with non-hydraulic limes except in areas where the limestone burnt for lime such as Lias limestone, contains a fairly high percentage of clay when the resulting lime may be semi-hydraulic.

Before continuing it would be well to consider one other property of sand which has practical importance. If water is added to dry sand which has in itself no tensile strength the mixture becomes steadily stronger as the surface tension of the liquid holds the grains tohether until the liquid forms a continuum at which point the sand becomes a quick-sand and will flow as a liquid. Thus the amount of water added to a sand-cement mix is critical depending on whether the mortar is to be worked with a trowel or poured as in concrete.

Chemical Analysis. The chemical analysis of a mortar provides two items of information a. the weight of insoluble material and b. the weight of Calcium oxide. Before either item can be used, weights must be converted to volumes and some assumptions about the source of both the insoluble and soluble material must be made. Firstly the insoluble fraction of a mortar will consist mainly of SiO_2 in the form of sand but often with additives such brick, tile or other silicates. Secondly the soluble fraction may include additives such as chalk, limestone and shell. A petrological examination of a mortar can indicate the proportion of sand present but though the presence of additives can be noted their percentage volume cannot be easily recorded, and such additives as clay or finely powdered chalk may not be recognised at all.

Thus, in order to combine the two methods of analysis certain assumptions and adjustments need to be made. Firstly the weight of insoluble material must be converted to volume i.e. 100 grams of insoluble material is assumed to represent 40cc of silica in the form of sand. The sand grains are assumed to be spherical and of uniform diameter so that the actual volume of sand is increased by the presence of voids to 52%.

The weight of CaO must be converted to volume of lime. Comparison of volume of sand to volume of lime should indicate the composition of the dry mix i.e. 100cc of mortar made up of 75% sand and 25% lime will be a 3-1 mix. The percentage volume of sand in the final set mortar 3-1 mix should be about 31% and in a 4-1 mix about 35%, in a 1-1 mix about 17%.

The estimate of sand volume by direct count is liable to be inaccurate but in practice compares reasonably well with that obtained by chemical analysis.

The size and shape of the sand grains cannot be determined by chemical analysis nor can the sand grading, and when the sand grains are measured by micrometer they are assumed to be spherical which is rarely the case.

Petrological Analysis. A thin layer of the mortar is examined under the microscope. By superposing a centimeter grid it is possible to estimate the number of sand grains per cc and so the percentage volume of sand in the mortar. Additives of material other than sand can be noted. The diameter of a random selection of sand grains is measured my micrometer (wherever possible not less than 100 grains) so that a cumulative percentage curve can be drawn. From this curve can be read the mode of the sand i.e. the

see Fig. 7

the diameter at 50% and the sand grading i.e. percentage of fine, medium and ~~hight~~ coarse. In order to check the accuracy of this method several samples of some mortars have been tested with consistant results.

Dicrepences between the results of chemical and petrological examination may be due to insoluble additives, soluble additives, clay, and leaching of the cement which is evident in some mortars.

Chemical and Petrological analyses have been carried out for the following samples,- See. Fig. 6.

1. Lillieshall Abbey, Shropshire (FWA 119)

The site is on Wenlock Limestone which if used for the cement would produce a semi-hydraulic cement.

Insoluble fraction- 58·02 grams = 44·5 cc sand

CaO - 17·68 grams =22·0 cc CaO = 113 cc cement

Thus the dry mix contained 67% sand (2-1 mix) and the set mortar 28% sand.

The volume of sand by count was 23·5% suggesting that the cement contained about 4·5% of silicates probably in the form of clay

The sand mode is 0·30mm diam, well-rounded.

The sand grading is 15-35-50 . Classified as M3.

Additives,- some quartz pebbles.

4. Orford Castle, Suffolk (FWA150)

The site is on Chalk so that the cement is likely to have been a fat lime.

Insoluble fraction- 39·40 grams =30cc sand

CaO - 39·85 grams = 50cc CaO =255 cc cement

Thus the dry mix contained37·5 % sand (1-2 mix), the set mortar 10·5 %

The volume of sand by count was 20% suggesting that the the cement contained 9·5% of added carbonates (see additives)

Sand mode - 0·32mm diam

Sand grading - 5-40-55 . Classified as a rendering (R)

Additives - much chalk, shell, sandstone fragments.

5. Farnham Castle, Surrey (FWA118)

The site is on Chalk so that the cement was probably a fat lime.

Insoluble fraction - 75·18 grams = 58cc sand

CaO - 11·48 grams = 14·4 cc CaO = 92cc cement

Thus the dry mix contained 80% of sand (a 4-1 mix)

The set cement contained 43% sand

Volume of sand by count - 44% suggesting that the mix contained no added silicates.

Sand mode - 0·42 mm diam, coarse, subangular

Sand grading - 0-20-80 Classified as M4

Additives - quartz pebbles, chalk, shell, ironstone.

6. <u>Sherborne Castle</u>, Dorset (FWA141)

The site is on oolitic limestone so that the cement was probably a fat lime.

Insoluble fraction - 43·10 grams = 33 cc sand

CaO - 28·56 grams = 35·5 cc CaO = 225 cc cement

The dry mix contained 48% sand (1-1 mix)

The set cement - 15·4% sand. Volume of sand by count - 12·6% suggesting that the mix contained about 3% of additional silica.

Sand mode - 0·06 mm diam, exceptionally fine-grained, well-rounded.

Sand grading - 85-10-5. Classified as a rendering (R)

Additives - quartz pebbles and chalk.

7. <u>Roman Wall, St.Albans</u>, Herts. (FWA50)

The site is on Chalk so the the lime was probably a fat lime.

Insoluble fraction - 65·36 grams = 50cc sand

CaO - 16·41 grams = 20·5 cc CaO = 106 cc cement

The dry mix contained 71% sand (a 3-1 mix)

The set cement contained 32% sand. Volume of sand by count - 33·5 %

Sand mode - 0·435 mm diam. a coarse sand.

Sand grading - 5-10-85. Classified as M4

Additives - quartz pebbles, flint, brick, ironstone.

8. <u>Bury St.Edmunds Abbey</u>, Suffolk (FWA117)

The site is on grey Chalk so that the cement was probably a semi-hydraulic with additional silicates of about 7·5%.

~~XMgxdrxxmix~~ Insoluble fraction - 70·00 grams = 54cc sand

CaO - 13·84 grams = 17·33cc CaO = 89cc cement

Dry mix contained 76% sand (3-1 mix)

Set mortar contained 37·5 % sand . Volume of sand by count - 30%

Sand mode - 0·295 mm diam.

Sand grading - 15-40-45. Classified as M3

Additives - quartz pebbles, flint, chalk, shell, ironstone.

9. <u>Okehampton Castle Chapel</u>, Devon (FWA145) See also 19.

The site is on Carboniferous Limestone. The cement was probably fat or semi-hydraulic lime.

Insoluble fraction- 59·90 grams = 46cc sand

CaO - 17·47 grams = 21·50 cc CaO = 112 cc cement.

Dry mix - 68% sand (2-1 mix)

Set mortar - 29% sand. Volume of sand by count - 25%

Sand mode - 0·480 nn diam. coarse.

Sand grading - 10-20-70. This is the fine fraction of a concrete.

Additives - crushed granite and a coarse aggregate of sandstone fragments

11. <u>Minster Lovell House</u>, Oxford (FWA 134)

The site is on oolitic limestone so that the cement was probably fat lime.

insoluble fraction - 45·42 grams = 35cc sand

CaO - 27·11 grams = 33·5 cc CaO = 172 cc cement.

Dry mix - 51% sand (1-1 mix)

Set mortar - 17% sand. Volume of sand by count - 8·4%

Sand mode - 0·31mm diam.

Sand grading - 20-30-50. Classified as a Plaster (P)

Additives - greensand, oolitic limestone, shell, quartz pebbles.

The excess silica in the chemical analysis is probably due partly to the addition of greensand and partly to the addition of clay.

12. <u>North Leigh Roman Villa</u>, Oxford. (FWA 142)

The site is on oolitic limestone so that the cement was probably a fat lime.

Insoluble fraction - 37·44 grams. = 29cc sand.

CaO - 30·58 grams = 38cc CaO = 196 cc cement.

Dry mix - 43·5 % sand (1-1 mix)

Set mortar - 13% sand. Volume of sand by count = 10·4%

Sand mode - 0·410mm diam. coarse.

Sand grading 5-20-75. This is the fine fraction of a concrete. The coarse aggregate consists of limestone, flint and ironstone.

13. <u>Houghton House,</u> Ampthill, Beds. (FWA 116)

The site is on Chalk so that the cement was probably fat lime.

Insoluble fraction 69·26 grams = 53·5 cc sand.

CaO [illegible]·21 grams = 1[illegible]·40 cc CaO = 84 cc cement

Dry mix - 76·5% sand (3-1 mix)

Set mortar - 30% sand. Volume of sand by count - 38%

Sand mode - 0·48mm diam. coarse, well-rounded.

Sand grading - 0-10-90. Classified as M4

Additives - quartz pebbles, flint, brick, chalk, shell.

14. <u>Castle Acre Priory</u>, Norfolk (FWA 103)

The site is on Chalk so that the cement was probably fat lime.

Insoluble fraction - 68·10 grams = 52cc sand.

CaO - 15·45 grams = 19·2 cc CaO = 99 cc cement

Dry mix - 74% sand (3-1 mix)

Set mortar - 34·5% sand. Volume of sand by count - 39·5%.

Sand mode - 0·26mm diam. ; subangular

Sand grading 30-45-25. Classified as M2

Additives - Brick, chalk, ironstone. The chalk addition was probably about 5%.

A personally collected sample from this site (FWA 113) had sand mode 0·26mm diam, and a grading of 25-45-30. The sand content was 40%.

15. Castle Rising, Norfolk. (FWA 135)

The site is on Lower Greensand. The cement was probably a fat lime made from Chalk. A little oolitic limestone appears to have been added to the mix.

Insoluble fraction - 70·94 grams = 54·5 cc sand.

CaO - 12·71 " = 15·8 cc CaO = 81 cc cement.

Dry mix - 78% sand (4-1 mix)

Set mortar - 40·5 % sand . Volume of sand by count - 41%

Sand mode - 0·49 mm diam., coarse, well-rounded.

Sand grading - 0-20-80, Classified as M4

Additives - Quartz pebbles, limestone, ironstone.

16. Framlingham Castle, Suffolk (FWA 127)

The site is on Chalk so the cement was probably a fat lime.

Insoluble fraction - 73·88 gms. = 57 cc sand.

CaO - 12·49 gms. = 15·70 cc CaO = 81 cc cement.

Dry mix - 78% sand (4-1 mix)

Set mortar - 41·5 % sand. Volume of sand by count - 38·5 %.

Sand mode - 0·37 mm diam. subangular.

Sand grading - 5-25-70. Classified as M4

Additives - Quartz pebbles, flint, brick,(probably about 3%)

17. Berkhamstead Castle, Hertfordshire, (FWA 132)

The site is on Chalk so the cement was probably a fat lime.

Insoluble fraction - 55·84 gms. = 43 cc sand.

CaO - 21·55 gms. = 26·5 cc CaO = 138 cc cement.

Dry mix - 62% sand (2-1 mix)

Set mortar - 23·5 % sand. Volume of sand by count - 23% .

Sand mode - 0·18 mm diam. a fine-grained sand.

Sand grading - 60-20-20. Classified as M1 but may be a rendering.

Additives - Brick and chalk.

18. Leiston Abbey, Suffolk. (FWA 149) See also 24.

The site is on Chalk so that the cement was probably a fat lime.

Insoluble fraction - 70·90 gms. = 55 cc sand.

CaO - 13·66 gms. = 17 cc CaO = 88 cc cement.

Dry mix - 76·5 % sand (3-1 mix)

Set mortar - 38·5 % sand. Volume of sand by count - 31·5 %.

Sand mode - 0·10 mm diam. Excessively fine grained, subangular.

Sand grading - 80-10-10. Non-typical, classified as E.

Additives - Quartz pebbles, calcite.

20. St.Olave's Priory, Herring Fleet, Suffolk. (FWA 102)

The site is on Chalk so that the cement was probably a fat lime.

No chemical analysis.

Sand in set mortar - 43% (a 4-1 mix)

Sand ~~grading~~ mode - 0·41 mm diam.

Sand grading - 5-20-75. Classified as M4.

Additives, quartz pebbles.

21. Greyfriars Cloisters, Great Yarmouth, Norfolk. (FWA 137)

The site is on Chalk so that the cement as probably a fat lime.

No chemical analysis.

Sand in set mortar - 32·5 % (a 2-1 mix)

Sand mode - 0·41 mm diam.

Sand grading - 0-20-80. Classified as M4.

Additives - quartz, flint and chalk.

22. Thetford Priory, Norfolk. (FWA 126) see 32.

The site is on Chalk so that the cement was probably a fat lime.

No chemical analysis.

Sand in set mortar - 41·5 % (a 4-1 mix)

Sand mode - 0·32 mm diam.

Sand grading - 5-35-60. Classified as M3.

Additives - flint, brick, chalk and shell.

23. Old Wardour Castle, Wiltshire. (FWA 115)

The site is on Upper Greensand. The cement was probably made from the neighbouring Chalk so that the cement may have been a fat lime.

No chemical analysis.

Sand in set mortar - 21% (a 1-1 mix)

Sand mode - 0·115 mm diam. excessively fine-grained.

Sand grading - 90-10-0. Badly sorted. Classified as E but probably a rendering.

Additives - much chalk.

25. Ewenny Priory, Glamorgan. (FWA 148)

The site is on Carboniferous Limestone. The cement probably semi-hydraulic.

No chemical analysis.

Sand in set mortar - 32% . (a 2-1 mix).

Sand mode - 0·40 mm diam.

Sand grading - 5-20-75, coarse sand. Classified as M4

Additives - limestone.

26. St.David's Palace, Pembroke. (FWA 140)

The site is on Carboniferous Limestone so that the cement was probably semi-hydraulic.

No chemical analysis.

Sand in set mortar - 3~~7~~2·5 % (a 2-1 mix)

Sand mode - 0·25 mm diam.

Sand grading 30-45-25. Classified as M2.

Additives - quartz pebbles and shell.

27. Cow Tower, Norwich, Norfolk. (FWA 138)

The site is on Chalk, cement probably a fat lime.

No chemical analysis.

Sand in set mortar - 25·5 %. (a 1-1 mix)

Sand mode - 0·41 mm diam.

Sand grading - 10-20-70, coarse sand. Classified as M4

Additives - quartz pebbles, flint, chalk, ironstone.

28. Binham Priory, Norfolk. (FWA 129)

The site is on Chalk, cement probably a fat lime.

No chemical analysis.

Sand in set mortar - 36·5 % (a 3-1 mix)

Sand mode - 0·36 mm diam.

Sand grading - 5-25-70 . Classified as M4.

Additives - flint, chalk, ironstone.

29. Caistor Roman Town, Norfolk. (FWA 139)

No chemical analysis. The site is on Chalk.

Sand in set mortar - 43% (a 4-1 mix)

Sand mode - 0·275 mm diam.

Sand grading - 25-35-40. This is the fine aggregate of a concrete robably probably made with a fat lime~~y~~ cement

30. Baconsthorpe Castle, Norfolk. (FWA 146)

A second sample was collected personally - FWA 109.

The site is on Chalk , cement probably a fat lime.

No chemical analysis .

Sand mode - 0·37mm diam. (146). 0·39 mm diam. (109)

Sand grading - 10-20-70 (146). 5-30-65 (109). Classified as a rendering. R.

Sand in set mix - 19% (146), 24% (109), (about a 1-1 mix)

Additives - quartz pebbles, flint, limestone, ironstone.

31. Burgh Castle, Suffolk. (FWA 114)

The site is on Chalk, cement ppobably a fat lime.

No chemical analysis.

Sand in set mortar - 22·5 % (a 1-1 mix)

Sand mode - 0·44 mm diam.

Sand grading - 5-15-80. Coarse. This is the fine aggragate of a concrete the coarse aggregate consisted of quartz pebbles, flint, brick and chalk

32. Thetford Priory, Norfolk (FWA 130), see 22.

33. Neath Abbey, Glamorgan. (FWA 151)

The site is on Carboniferous Limestone so that the cement was probably semi-hydraulic.

No chemical analysis.

Sand in set mortar - 3·6%. (a 1-13 mix)

Sand mode - 0·30 mm diam.

Sand grading - 15-40-45. Classified as a plaster , P.

Additives - some rock fragments.

34. Cilgerran Castle, Cardigan. (FWA 144)

No chemical analysis.

Sand in set mortar - 7% . Sand mode - 0·34 mm diam.

Sand grading - 10-30-60. This is the fine aggregate of a concrete the coarse aggregate of which consists of quartz pebbles, slate and schist fragments.

35. Denny Abbey, Cambridgeshire. (FWA 128)

The site is on oolitic limestone so that the cement is probably a fat lime.

No chemical analysis.

Sand in set mortar - 38·5 % (a 3-1 mix)

Sand mode - 0·37 mm diam.

Sand grading - 5-25-70. Classified as M4.

Additives - quartz pebbles, flint .

36. Weeting Castle, Norfolk. (FWA 131)

The site is on Chalk , the cement probably a fat lime.

No chemical analysis.

Sand in set mortar - 39% (a 3-1 mix)

Sand mode - 0·30 mm diam.

Sand grading - 15-40-45. Classified as M3.

Additives - quartz pebbles, flint, ironstone.

37. Llanstephan Castle, Carmarthen. (FWA 147)

The site is on Carboniferous Limestone so that the cement was ~~probably~~ probably a semi-hydraulic.

No chemical analysis.

Sand in set mortar - 33·5 %. (about 2-1 mix)

Sand grade - 0·16 mm diam.

Sand grading - 75-25-0. This is a concrete in which the coarse aggregate consists of fragments of Carboniferous Limestone.

38 & 39. Caerleon Roman Wall, Monmouth.

No chemical analysis.

This is a most peculiar concrete. Both fine and coarse aggregates consist Carboniferous Limestone and some Lias Limestone chips set in cement. No sand was used

40. Oxwich Castle, Glamorgan. (FWA 136)

The site is on Carboniferous Limestone. The cement probably hydraulic.

No chemical analysis.

Sand in set cement - 9% ((a 1-~~10~~ 4 mix)

Sand ~~xxxxxx~~ mode - 0·295 mm diam.

Sand grading - 10-50-40. This is a plaster with additives of brick and clay.

41. Winchester Cathedral, Hampshire. (FWA 143)

The site is on Chalk. The cement ~~xxxxxx~~ probably fat lime.

No chemical analysis.

Sand in set cement - 12·5 % (1-3 mix)

Sand mode - 0·34 mm diam.

Sand grading - 50-30-65. This is a rendering.

Additives - quartz pebbles, flint, chalk.

42. York Minster, Yorkshire. (FWA 133)

The materials used for the cement were probably Magnesian Limestone and Chalk.

No chemical analysis.

Sand in set cement - 16% (a 1-2 mix)

Sand mode - 0·31 mm diam.

Sand grading - 15-35-50. This is a rendering.

Additives - quartz pebbles, brick, limestone and chalk.

Summary of results to date,-

1. Seven samples of modern mortar have been analysed for comparison. Three of these were known to be standard 3-1 mixes, three appeared to be a 4-1 mix. The remaining sample contained less sand and was probably a 2-1 mix, it certainly was harder than the others.

The sand mode ranged from 0·28mm diam to 0·31 mm diam. and the sand grading put six in the M3 group and one in M2 (see below).

2. Mortars (M). Davey (1961) reporting on a study of some Roman mortars appears to have included gravels a part of the sand content," sand etc. < 19 mm. diam." It may be that most of the samples included in this analysis were what here would be classified as concrete. He states that the aggregate for a mortar should be less than 3/16 th. inch (5 mm) diam.In the present

study it was unusual to find sand grains larger than 1·00 mm diam.

In what here is regarded as a true mortar the volume of sand is between 30 and 50%. The sand mode and grading have been used to distinguish four grades of martar and it appears as if these grades may have some historical significance. For example most of the mortars in group M1 could be Saxon, whilst those in group M4 are mostly Roman or 12th.Cent.

Fig.5

M1. Mortars in which the sand mode is 0·15-0·22mm dia. (average of 21 samples 0·20mm diam.). The sand grading shows a predominance of fine sand (average grading 55-35-10.

Fig.1

Brixworth Church - 17 samples, St.Peter's Street, Northampton - 2 samples, Little Somborne - 1 sample, Berkhampstead Castle - 1 sample.

M2. Mortars in which the sand mode is 0·22-0·275mm diam. (average of 17 samples 0·25mm diam). The sand grading shows a predominance of medium sand average grading - 30-50-20.

Fig 2

Brixworth Church - 13 samples, Castle Acre Priory - 2 samples, St.David's Palace - 1 sample, a modern building - 1 sample.

M3. Mortars in which the sand mode is 0·275-0·350mm diam. (average of 23 samples - 0·31mm diam.). The sand grading shows medium and coarse sand in more or less equal quantities - 15-40-45.

Fig.3

Brixworth Church - 8 samples, modern building - 6 samples, Lillieshall Abbey -2 samples, St.Augustine's Abbey - 2 samples, Thetford Priory - 2 samples , and single samples from Bury St.Edmund's Abbey, Weeting Castle and Orford Castle.

M4. Mortars in which the sand mode is 0·35-0·49mm diam. (average of 26 samples - 0·41 mm diam.). The sand grading shows a predominance of coarse sand - 0-20-80.

Fig.4

St.Augustines's Abbey - 7 samples, Brixworth Church - 3 samples, Baconsthorpe Castle and Wolvesey Palace - 2 samples from each. Single samples from Roman Wall St.Albans; St.Olave's Priory; Roman Wall, Lincoln; Houghton House; Farnham Castle; Thetford Priory; Denney Abbey; Binham Priory; Castle Rising; Greyfriars Cloisters; Cow Tower, Norwich; Ewenny Priory.

Renderings. A mixture of sand and cement in which the the volume of sand is 10-30 %

R1. Sand mode mostly about 0·25 mm diam. (range 0·175-0·30mm diam,)

R2. Five samples of rendering from St.Agustine's Abbey contained coarse sand i.e. the mode was between 0·30 and 0·49 mm diam. Similar renderings were seen from York Minster, Winchester Cathedral and Wolvesey Palace.

N.B. At Rudston Villa the smaller tesserae (1cm) were set in a bed of R2 type rendering (the sand mode was 0·52-0·57mm diam.), whereas the larger tesserae (2 cm) were set in a fine sand rendering (R1, sand mode 0·22- 0·23mm diam.). ? Two periods of construction.

<u>Plaster</u>. ~~The~~ 19 of the samples examined all had a low sand content (less than 10%) and one sample from Ludgershall contained no sand, it appeared to be a mixture of crushed chalk and cement. In general the sand was fine-grained (average mode - 0·265mm diam.) and there was a considerable amount of calcareous material added. None were gypsum cements and only one (Castle Rising) contained hair.

<u>Concrete</u>. So far only six samples have been examined and there is considerable variation. In general the sand is rather coarse but a Roman concrete from Caerleon contained no sand, it consisted of stone fragments in cement.

A concrete from St.Peter's Street, Northampton contained unusually fine-grained sand with a coarse aggregate of limestone fragments.

<u>Non-typical Mortars</u>.(E) A few of the mortars could not be easily fitted into the classification outlined above generally because the sand was ungraded. For instance that from Leiston Abbey contained 80% of sand less than 0·21 mm diam. One of the samples from St.Augustine's Abbey had 35% of fine sand, 45% of coarse sand and only 20% in the medium grade.

An unusual sample from Brixworth contained a lot of hair but the percentage of sand was much too high for it to be classified as a plaster.

<u>Postscript</u>. The results of this investigation so far are encouraging. They suggest that a useful classification of mertars and allied sbstances can be found. Moreover, there appears to be the possibility of a rough dating of mortars.

It is also obvious that many more examples need to be studied particularly of firmly dated material before any further assumptions can be made.

Petrological and chemical analyses can both contribute some evidence of the original composition of the mortar, but it is debatable whether or not the latter are really essential.

Specimen work sheet for a fictitious site.

See Fig. 8.

St.Andrew's Abbey, Kent. (FWA xxx)

The site is on Chalk so that the cement was probably a fat lime.

Number of sand grains per cc = 8,000 (20^3)

Additives - quartz pebbles, flint, some chalk.

Sand - a river or beach sand , well-rounded.

Sand grading,-

Grain diameter in Micrometer units.	Number.	%	cumulative %
1	0	0	0
2	3	3	3
3	11	11	14
4	20	20	34
5	30	30	64
6	20	20	84
7	12	12	96
8.	3	3	99
9	1	1	100
	100		

Sand mode - 0·28 mm diam.

Sand grading - 15-50-35, a medium sand. Classified as M3

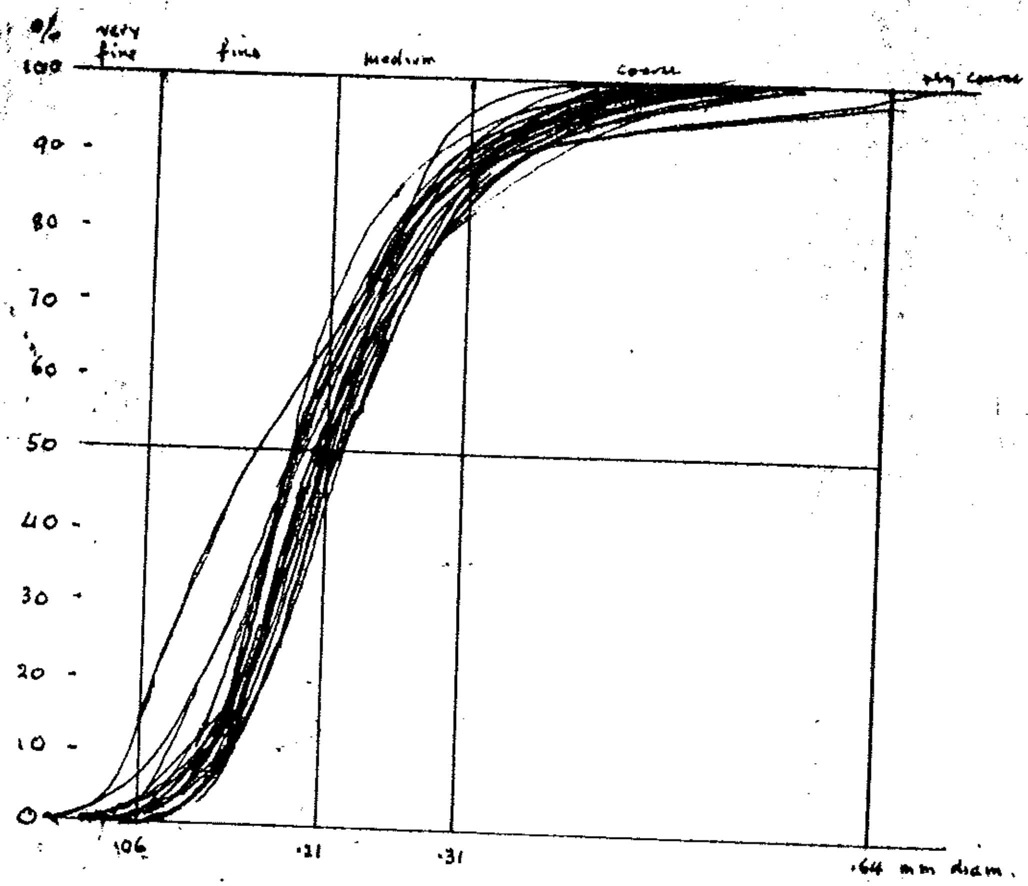
Volume of sand in set mortar - 28·5 % (a 2-1 mix)

M1

Fig. 1

Sand grading of 21 mortars.

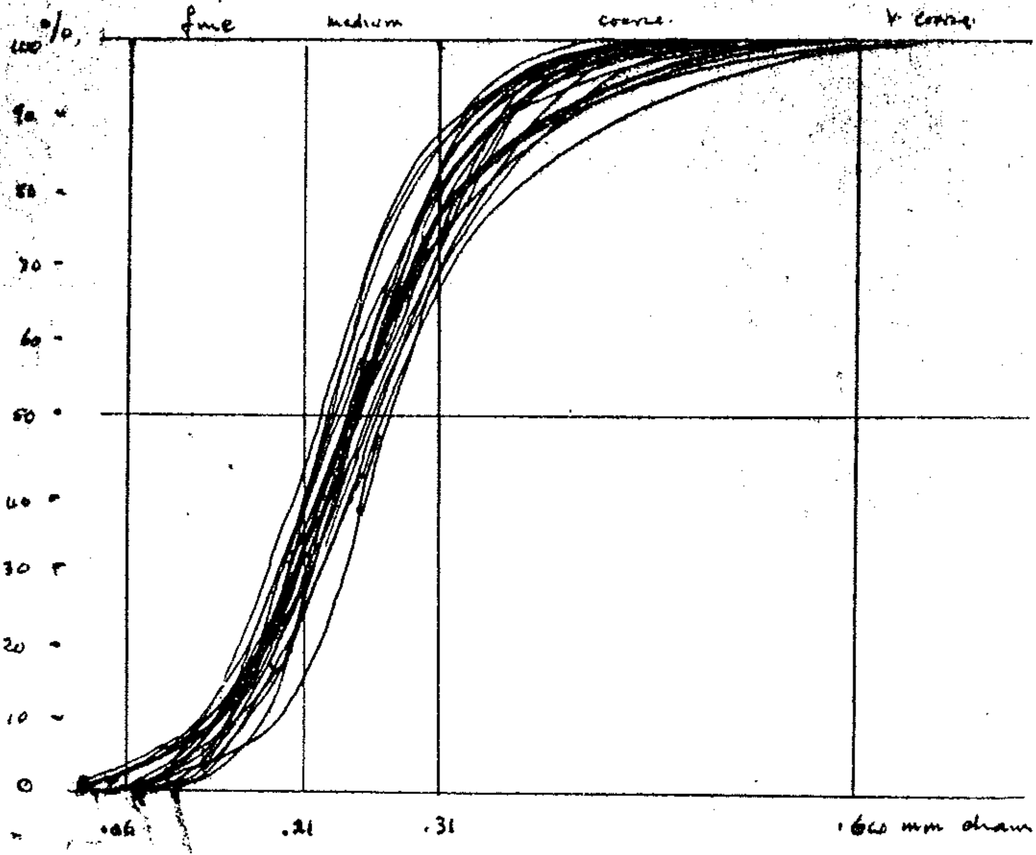
Cumulative % curves



mode 0·20 mm

M2. Fig. 2

Sand grading of ~~22~~ 17 mortars
Cumulative % curves



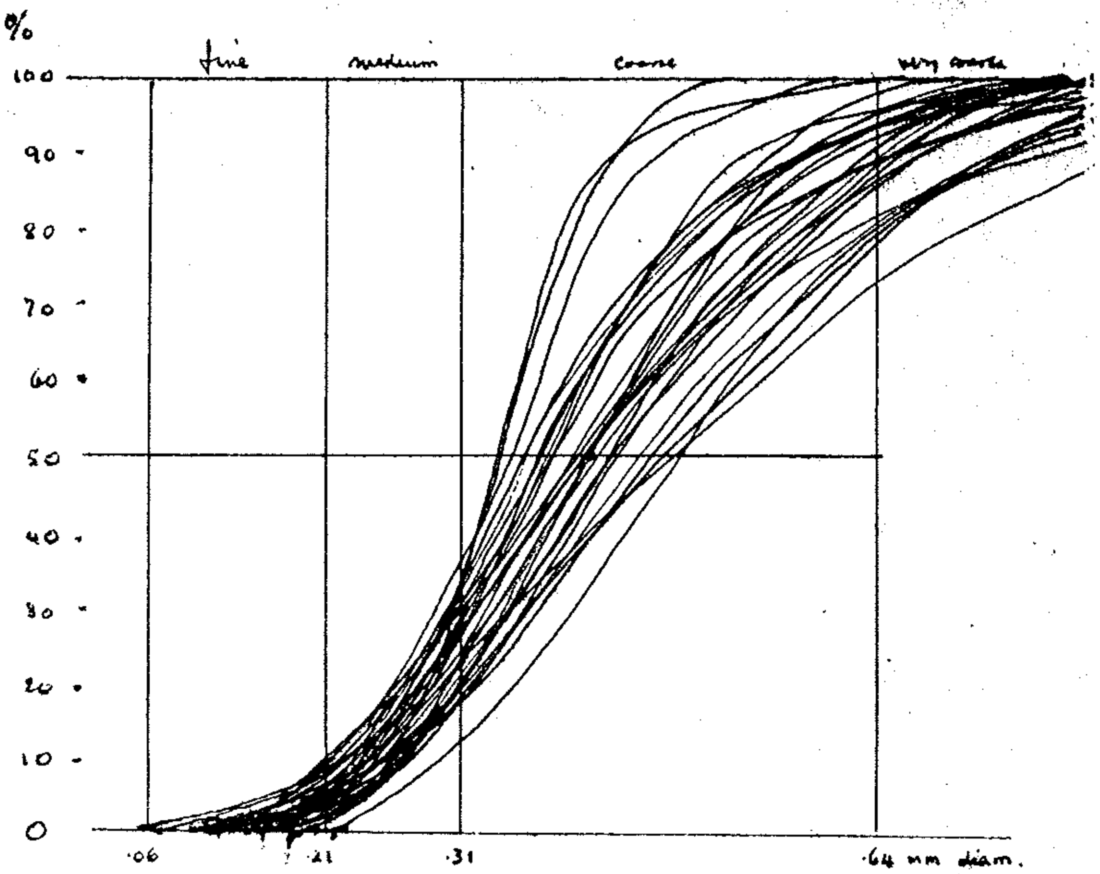
mode 0·25 mm

Fig. 4

M'4

Sand grading of ~~30~~ 26 mortars.

Cumulative % curves



mode 0·41 mm.

Fig. 5

Sand Grading.

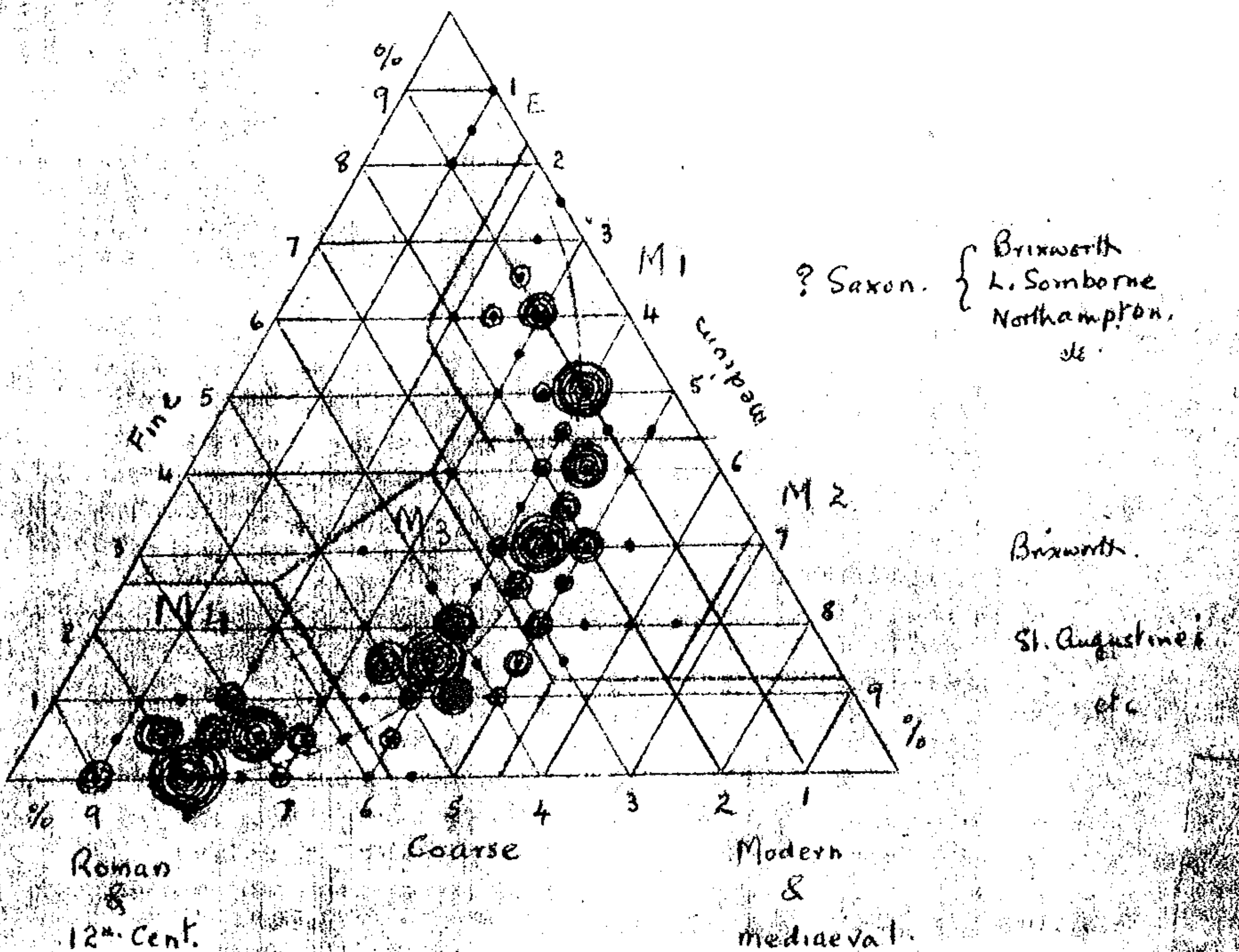
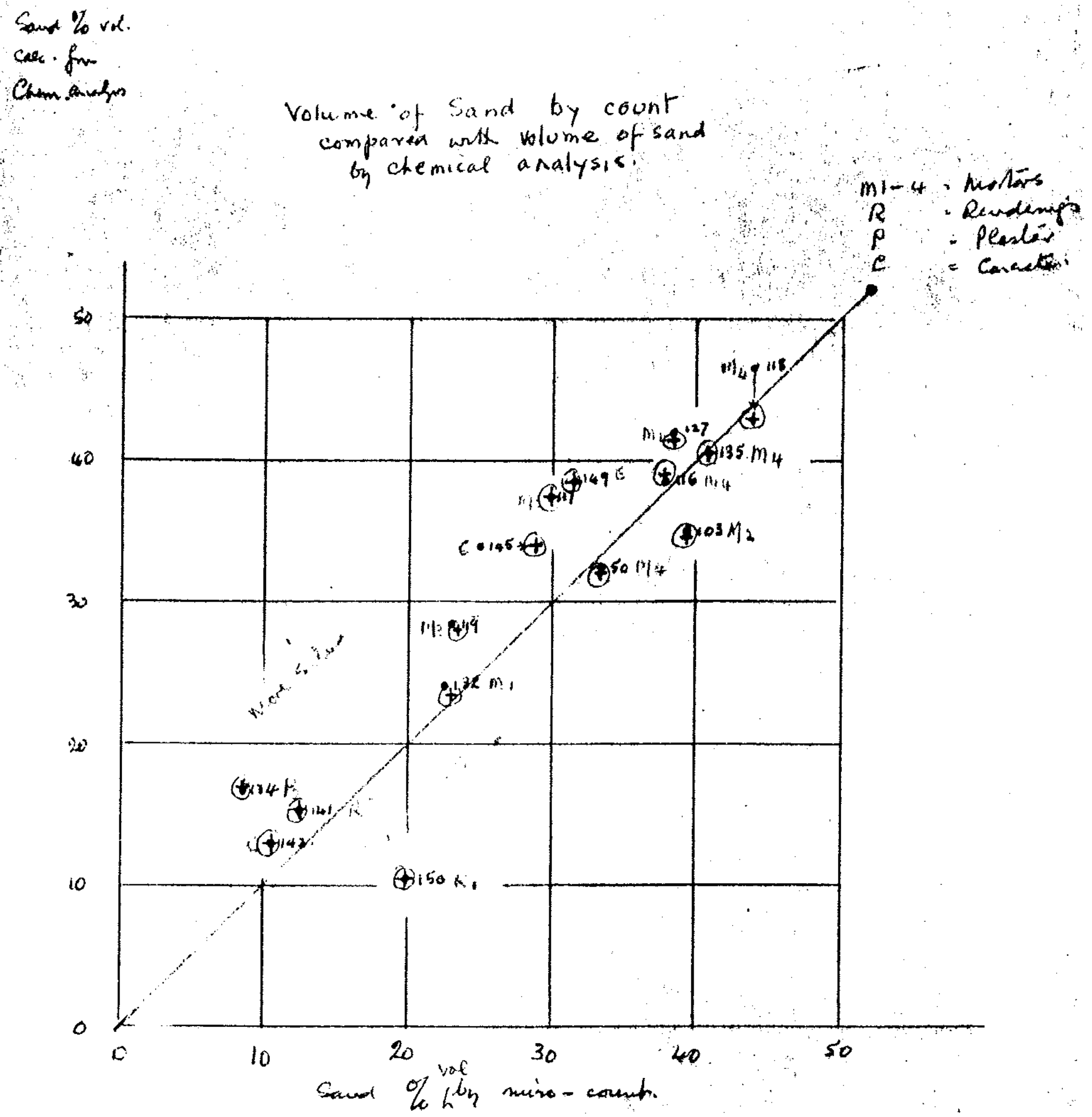
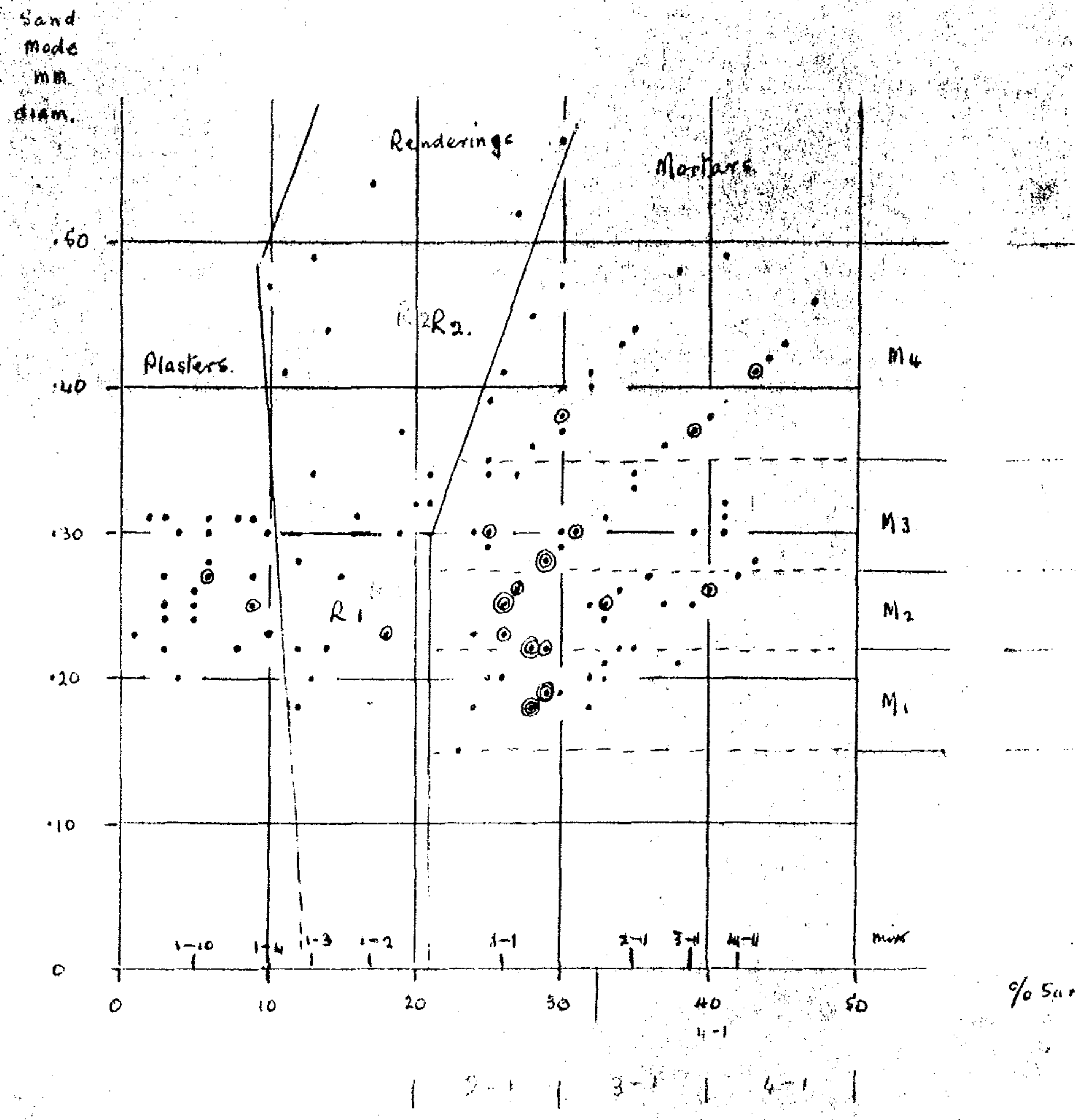


Fig. 6



Sand % vol. calc. from Chem. analysis
Volume of Sand by count compared with volume of sand by chemical analysis.
M1-4 = Mortars
R = Renderings
P = Plasters
C = Concretes
0
10
20
30
40
50
Sand % vol. by micro-count.

Percentage of Sand in set mortar compared with Sand mode.



xxx. St. George's Abbey. Kent.

Sand grains — 8000 per. cc.

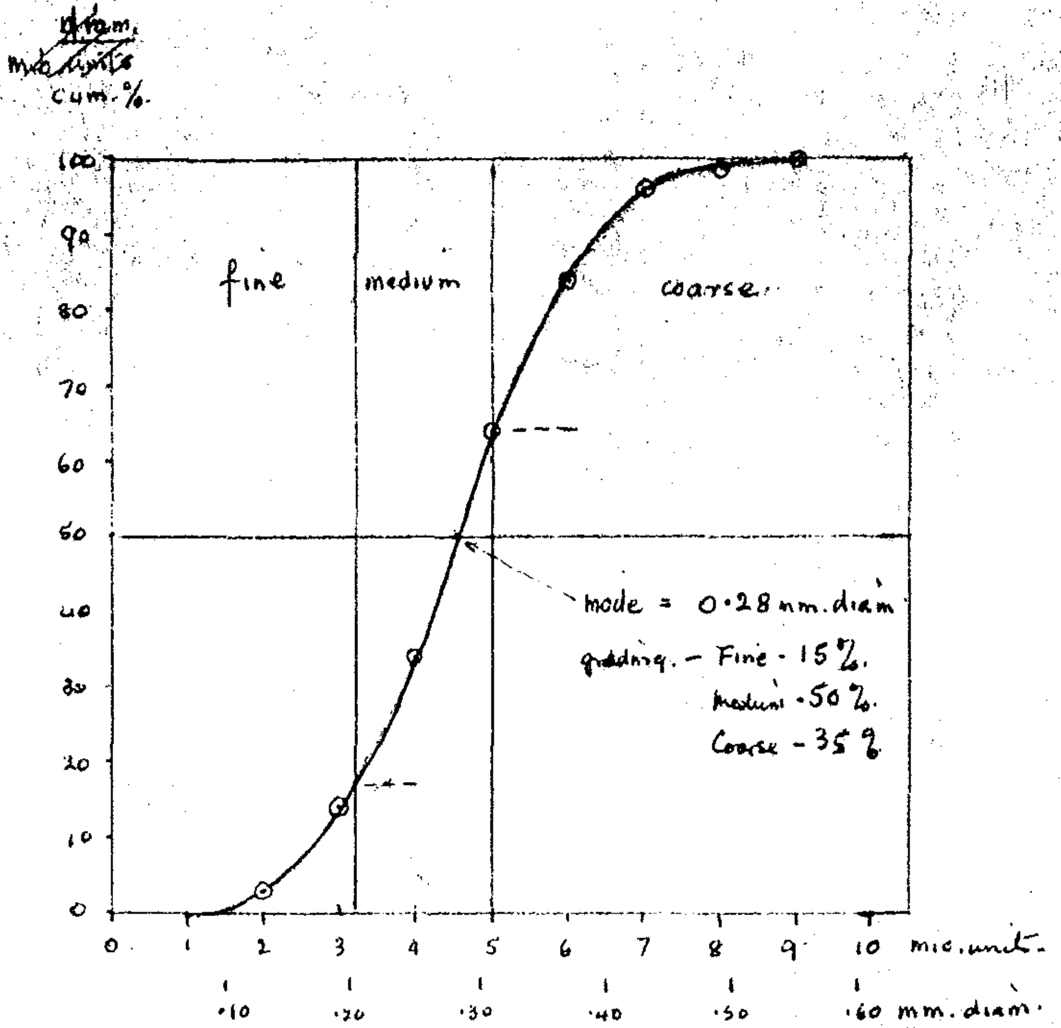


Fig. 8.