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ANALYTICAL INVESTIGATION OF TRADITIONAL LIME PLASTERS. THE CASE OF SARDINIA (ITALY)

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Abstract

The aim of this paper is to provide an overview of the nature of lime plasters of a region of Sardinia, Italy. Several samples of scratch coat and skim coat were collected from both external and internal parts and their study was assessed by employing a straightforward methodology. The conclusions are of practical implication for future conservation as the experimental analysis provided the following information: type of aggregate, ratios between binder and aggregate, calculation of aggregate grading envelopes for every sub-category, softness and management of water vapour, use of pozzolana, and non-hydraulicity of lime.

Keywords

Lime plaster, Sardinia, Italy, experimental analysis, aggregate, vernacular buildings

Introduction

The objective of this paper is to describe the results of the experimental analysis of interior and exterior lime renders of Campidano, a region of Sardinia. Nowadays lime is no longer used as a coating material, but is still found in several vernacular buildings of Campidano as it is seldom replaced or maintained (Figs. 1 and 2). A study carried out by the author shows that 42.7% of the vernacular mud brick buildings visited (310 in total) were still plastered with lime (historic plaster), 39.9% were plastered with cementitious coats, whilst only 6.6% were plastered with mud (historic plaster).

Selection of samples

The selection of the samples of lime render was carried out in buildings dating between 1900 and 1960, that were geographically distributed from across Campidano, and which were representative of the region under examination. Lime renders were sampled and classified as follows:

- (1) Twenty-seven samples were collected by the author from 16 different villages of Campidano. Sampling was undertaken by choosing typical, extreme, and marginal cases: internal scratch coats (5 samples), internal skim coats (7 samples), external scratch coats (5 samples), external skim coats (10 samples).
- (2) Three lime kilns were also visited and three natural samples of local limestone were collected.

Five samples were considered to be the minimum representative for the sub-groups. Selecting sets of four of such samples (interior skim, interior scratch, exterior scratch, and exterior skim) from one single building was often found to be impractical¹. Convincing owners to allow the sampling of their interior renders was also a complicated task. The author also found that detecting ideal buildings with both interior and exterior renders made of lime as a binder was a complicated task because hybrid types with inclusions of mud are quite common in Campidano. Furthermore, it is common to find interior and exterior lime renders made of single coats only. As a consequence of this, independent samples were collected. Unoccupied buildings were by and large the easiest target for sampling interior renders, as it would have been otherwise difficult to convince the occupiers to permit the taking of specimens from the inside of their dwellings. Collection was always tackled at a height of 1.2 metres from ground level.

Experimental analysis

Determination of carbonates content and analysis of aggregate

This test has a double purpose. The first aim is the calculation of the ratios between carbonate and aggregate; the second is the analysis of the aggregate in terms of its mineralogical composition, and also in terms of its grain size distribution.

The analysis of the carbonates content and of the aggregate was done following what explained by Teutonico (1985, 93): dissolution in HCl and sieving. Table 1 illustrates the percent amount of carbonates, gravel, sand, and impurities (silt and clay). Average values for the four tables were calculated and this allowed the design of the percent values of the ratios for every category.

It should be noted here that the dissolution method has two principal limitations. The

¹ It is important at this stage to define aggregate: in the context of lime renders the author refers to aggregate as the totality of gravel, sand, silt, and clay. In particular, the totality of silt, clay, and eventual organic matter is referred to in this study as impurities.

first is due to the dissolution of eventual calcareous aggregates and to the consequential misleading ratio between lime and aggregate (Ashurst 1983, 20; Teutonico 1985, 93). The second limitation is due to the fact that the apparent grain size analysis does not correspond to the actual one if calcareous aggregate is present in the mix. This is supported by Pearson (1992, 162) who explains that: 'A sample of the render weighing at least 100 grams may be sent to a laboratory for analysis and report for use as a guide to matching the original. However, analysis will only identify the constituent materials and may be misleading, as aggregates containing chalk or limestone will be included with the lime content to produce figures that indicate a high percentage of binder. The figures are thrown further into confusion if old, crushed mortar has been included in the mix. The analysis will not identify whether the lime was prepared from chalk or limestone or whether it was site-fired in a clamp or factory-made' (Pearson 1992, 162). A similar observation on the limitations of lime render analysis is also made by Ashurst (1983, 20) who explains that the presence of a misleading binder is a notorious problem. Another limitation, which implies the dissolution of lime renders in hydrochloric acid, is that the binder-to-aggregate ratios were traditionally calculated by *volume*, whilst laboratory experiments were conducted by *weight*.

Vianello (1987, 253) studied a method for the calculation of the carbonatic aggregate by soaking the sample into acetone, thus allowing the separation of the grains from the cementing agent. The matter is then wet-sieved through a 0.063 mm sieve. According to Vianello, the sieving allows the elimination of the finer particles which are considered to be made of only disaggregated binder. The dried aggregate is then sieved through a stack of sieves and its granulometry curve calculated. The method proposed by Vianello proved effective for his research on the historic mortars of the region around Venice (where aggregate was traditionally washed of all impurities), but is not applicable for the specific case of Sardinia (where aggregate was traditionally employed as quarried). In fact the wet-sieved matter would not only contain the disaggregated filler, but also the finer impurities such as clay and silt which would definitively influence the granulometry curve and the performance of the filler.

An effective methodology for the study of the grain size distribution curves of a population of samples is provided by Fadli (1995, 29-32) and is adopted here in this study. It consists in the grouping of all curves in order to create an S-shaped area (Fig 4). The two curves deriving from the perimeter of the area are defined by Fadli (1995, 29) as: *minimum curve*, or the entirety of the recorded minimum values; and *maximum curve*, or the entirety of the recorded maximum values (Fig. 4). The average of the entirety of values is defined as the *ideal curve*. The area under consideration, being asymmetric, can be corrected in order to allow the same of variation from both sides of the ideal curve. Another area, called *theoretical area*, as the zone with a high concentration of curves (Fig. 5), of which the average curve is the ideal one. The representation of the theoretical area was undertaken after calculating the following divergence values for every grain diameter:

$$D_{\max} = \%_{\max} - \%_{\text{med}}$$

$$D_{\min} = \%_{\text{med}} - \%_{\min}$$

$$D = \inf(D_{\max}; D_{\min})$$

The correction of the minimum and maximum values is then carried out through the following formulas:

$$\% \text{ max limit} = D + \%_{\text{med}}$$

$$\% \text{ min limit} = \%_{\text{med}} - D$$

These values are plotted in the semilogarithmic graph in the shape of two symmetric curves which delimit the theoretical area (Fig. 5), with the two new curves representing the limit values of the theoretical area. They demarcate an area that can be considered as grading envelope or reference zone. It should here be noted that the grading envelope, being the product of the analysis of a limited number of nine samples, is approximate and not rigid. It is in fact possible that samples which do not behave within the parameters of the zone are actually satisfactory in practice. The usefulness of a recommended zone derives from the fact that those soils which comply with it are more likely to behave satisfactorily than those which do not (Houben and Guillaud 1994, 127). The area on Fig. 5 has the limitation of being the result of the study of a limited population size. A more representative population size should be investigated in future research in order to allow a more precise plotting of the recommended zone for the specific area of Campidano.

Recommended zones were calculated for the four categories of samples: internal scratch coats, internal skim coats, external scratch coats, external skim coats (Figs. 7-10).

Hydraulic properties of lime

A main finding is related to the use of natural and artificial hydraulic limes in Campidano. Three representative limestone samples of about 200 gr were collected from the vicinity of lime kilns that were in use until the 1950s. After dissolution of the stone samples in hydrochloric acid, the average percentage of impurities of the three samples was calculated to be:

- (1) 3.3% (sample from shaft kiln located in Via Roma, Nuraminis);
- (2) 1.3% (sample from hillside kiln located between Monte Pireddu and Su Benatzu, Santadi);
- (3) 3.7% (sample from shaft kiln located in the north outskirts of Aquacadda).

This kind of analysis does not give any certainty about how limestone performed after firing (Wingate 1985, 37), but the figures above are indispensable for classifying the resulting limes as *fat* or *pure*, with *high calcium*, white in colour, with very fast setting, considerable expansion, and characterised by no setting in water [classification based on Teutonico (1997, 6)]. This small survey has another important outcome. It confirms the Mamuta's conclusion (1933, 14) that natural hydraulic lime was seldom intentionally produced in the island, but was rather imported from the peninsula. Furthermore, after the analysis of all samples of lime coats, external and internal, only one case showed the presence of artificial pozzolanic aggregate. A mix of sand and crushed roof tiles was found in one sample collected from Gonnese village. The analysis of the sample gave a percentage proportion of lime:sand:crushed tiles of 25.4:28.4:46.1. This ratio is extremely close to 1:1:2, which is the traditional mix of three parts aggregate and one part lime. This is also confirmed by the comparison of the proportion 1:3 with the average percent value on Table 1 (the exact ratio for exterior scratch coats being 1:3.1).

Lime renders as a complex porous system

Several important findings from the analysis of lime renders derive from the last line of

Table 1. Before discussing the results, a definition of softness of lime render is necessary. As a general rule, the softer the render, the higher the amount of sand and gravel and the lower the amount of lime. Table 1 reveals that interior wall surfaces were rendered with increasing hardness from the interior mud-brick wall face to the inside of the building. This is demonstrated by the fact that interior scratch coats have a lower content of sand and gravel than interior skim coats, whilst their calcium carbonate content is higher than that of skim coats. Table 1 further demonstrates that exterior lime surfaces were rendered with decreasing hardness from the external mud-brick wall face to the outside of the building. This is demonstrated by the fact that exterior scratch coats have a slightly higher content of sand and gravel than exterior skim coats, whilst their calcium carbonate content is lower than that of skim coats. The main conclusion drawn from this is that the traditional device for the protection of earthen buildings of Campidano seems to have been the use of two exterior coats with increasing softness from inside to outside and of two interior coats with decreasing softness from outside to inside. The theory proposed here is that the peculiarity of such a device is that it allows condensation to migrate outside the wall. Soft surfaces are usually more porous than hard coats and the more porous the render, the higher the managing of moisture through evaporation (Hughes 1986, 1). This is relevant in conservation terms because condensation in proximity of the internal coats can be five times higher than that in proximity of external coats (Massari 1993, 45). It was also calculated that, on average, interior scratch coats double in thickness the skim coats:

- the average thickness for the scratch coat is 1.8 cm;
- the average thickness for the skim coat is 0.91 cm.

Furthermore, exterior lime coats were found to be characterised by the following average thicknesses:

- the average thickness for the scratch coat is 1.24 cm;
- the average thickness for the skim coat is 0.54 cm.

Some samples contained soluble salts, probably due to employment of unwashed sand quarried from local beaches. Salt content analysis was carried out only on a limited number of samples by separating the water in which the sand was left to sediment. The solution of water was then left to evaporate. Salts were found in an average concentration of 1.5%.

Mixes for interior and exterior coats

The analysis of lime renders gave further useful information about the average ratios between lime and unwashed aggregate for the four categories (Table 1). Lime renders are rarely specified in historic documents, but what was unveiled by the author in archival records shows some disagreement. If in the archival records of the village of Quartu Sant'Elena the volumetric proportions of lime to aggregate for mortars and renders was found to be of 1:2 (ASQ 1868 and ASQ 1900), in those of Iglesias it was specified as 1:3 for the mortar and of 1:2.25 for lime render (ASI 1906). Furthermore, other records shows that the proportion between lime and pozzolanic additive was specified as 1:2.3 (ASQ 1900). The average ratios for the data read in the archival records of Quartu Sant Elena and Iglesias is 32%:67.4%. This can be compared to the

average ratio of the four categories on Table 1 which is 26.7%:70.1%. Archival documents did not specify two different ratios for skim and scratch coats, but only a single ratio for both cases. This is the reason why the overall average value for the four cases of Table 1 was used for comparison here. This slight difference between the average archival ratio and that calculated with the 27 samples analysed by the author can be explained as:

- (1) A certain degree of arbitrariness by Master Craftsmen when preparing lime mortar mixes;
- (2) A too-limited number of archival documents which do not properly represent the area under examination;
- (3) Disagreement between official records and what was actually carried out in the site;
- (4) Disagreement between official records and what was actually carried out by Master Craftsmen in more rural settings than those of Quartu Sant Elena and Iglesias.

Presence of impurities

Another important outcome can be revealed by the analysis of the aggregate obtained after dissolution. It is clear from its analysis that the aggregate was generally mixed to the binder as quarried. Washing all impurities such as clay and silt was not a common practice in traditional Campidano. The reason for this may be due to the fact that aggregate was dug from rivers and streams, and never made from crushed rock. Its nature was therefore low in fines and impurities, and washing was not considered necessary. When referring to impurities, Ellis (2000, 31) explains that many of these materials had a positive or beneficial physical and chemical effect on the performance and durability of traditional mortars. This view is strongly supported by local craftsmen who explain that unwashed aggregate should be preferred to the washed sharp sand typical of cementitious mortars when making the mix for lime renders. However, this contradicts what was directly observed by the author in modern conservation practices in Sardinia. After the advent of cement, aggregate was agreed to be washed of all impurities with a consequential lack of finer matter in the granulometry curve.

Conclusions from the analysis of lime renders

The results of the analysis of lime renders have two practical implications. The first concerns the geological nature of the limestone, and the second regards the composition of lime renders.

The percent of impurities is such that the lime can be classified as non-hydraulic, fat, pure or with high calcium. This type of lime is characterised by a very fast slaking time, considerable expansion, and by a white colour. The dissolution of renders in hydrochloric acid shows that the skim and scratch coats of both internal and external surfaces have variable lime:aggregate ratio which is a function of the type of coat. The experimental analysis therefore confirms that the typical 1:3 ratio is not standard in Campidano. The reason for this finding is that external and internal coats are designed to form a porous system. Internal coats are characterised by increasing softness from the limewash to the scratch coat, whilst external coats show increasing softness from

the scratch coat to the limewash. It is proposed here that this porous system allows both the condensation present in the internal wall surface and the moisture present in the mud brick to be driven outside the building. Other useful findings are represented by the recommended zones for the granulometry curves of the aggregates of skim and scratch coats of both interior and exterior renders. Furthermore, the presence of impurities in the aggregate demonstrates that the traditional craftsmen were correct: river sand was commonly employed and was rarely washed of all impurities before use. To summarise, the main findings of these tests were:

- (1) natural hydraulic lime does not seem to have been used in twentieth-century Campidano, whilst it seems evident that artificial hydraulic lime might have had a small degree of popularity;
- (2) binder/aggregate ratios were calculated for skim and scratch coats of both internal and external surfaces. A strong emphasis was given on the evaluation of methods employed for their calculation and this is important in terms of future research;
- (3) the recommended zones for skim and scratch coats of both exterior and interior surfaces were calculated;
- (4) lime renders were traditionally applied to both internal and external sides of *làdiri* walls in order to form a complex porous system of coats which allows condensation to be driven off from the interior of the building;
- (5) sand was traditionally employed as quarried because impurities were found in the majority of the analysed samples;
- (6) the aggregate used for the making of lime renders of Campidano is river sand which for the majority of cases originated from the decomposition of granites. As a consequence of this, quartz and feldspars are mainly represented and mica, soapstone and slate are sparse.

Finally, it is hoped that further research on characteristics of lime as a binder be carried out in the future and that this study be the basis for more sophisticated analytical work.

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ARCHIVAL RECORDS

Abbreviations: ASQ (Archivio Storico Comunale di Quartu Sant'Elena), ASI (Archivio Storico di Iglesias).

ASI 1906. Cartella No 985. Capitolato Speciale d'Appalto, Lavori di Restauro della Cattedrale d'Iglesias. 18 February 1906

ASQ 1868. Cat X, Classe 9, Cartella No 80, Progetti Tecnici. Progetto delle Opere d'Ampliamento della Casa Comunale di Quartu Sant'Elena, Capitolato d'Appalto. 14 June 1868

ASQ 1900. Cat X-b, fascicolo 146. Macello da Eseguirsi nel Comune di Quartu Sant'Elena, Capitolato d'Appalto. 1900



Fig. 1. An earthen building of Campidano showing lime render on mud brick masonry

(village of Monserrato).



Fig. 2. Sampling of lime render was done to cause minimum destruction, and mostly in building with high decay levels such as this one in the village of Sinnai.

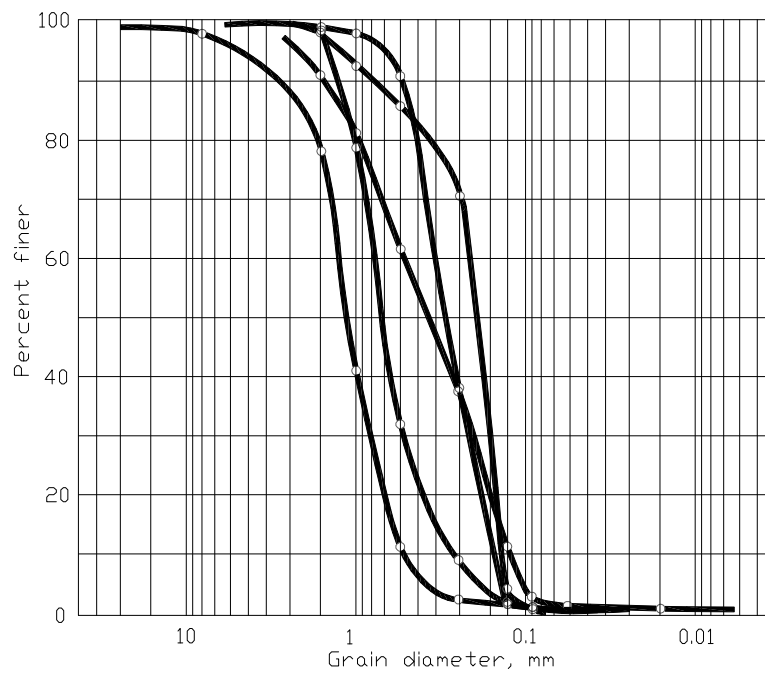


Fig. 3. Grouping of granulometry curves (interior scratch coats)

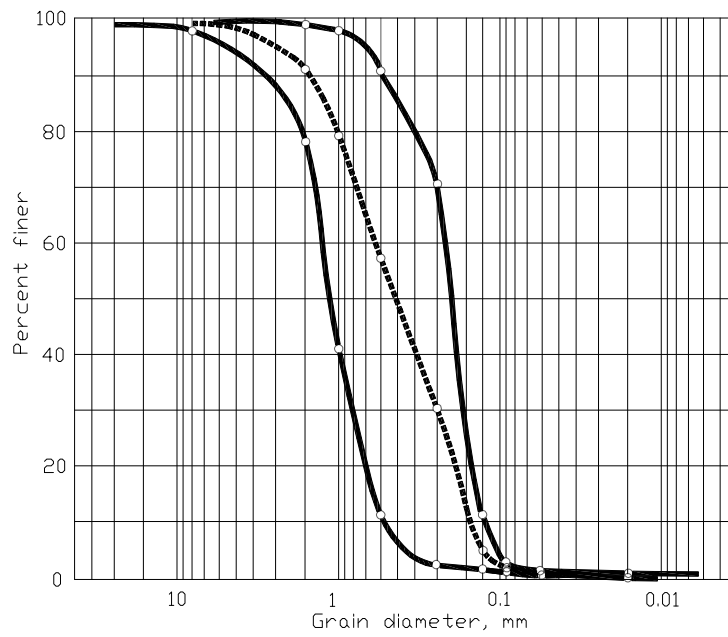


Fig. 4. Minimum, maximum, and ideal curve as derived from the perimeter of curves in Fig. 3

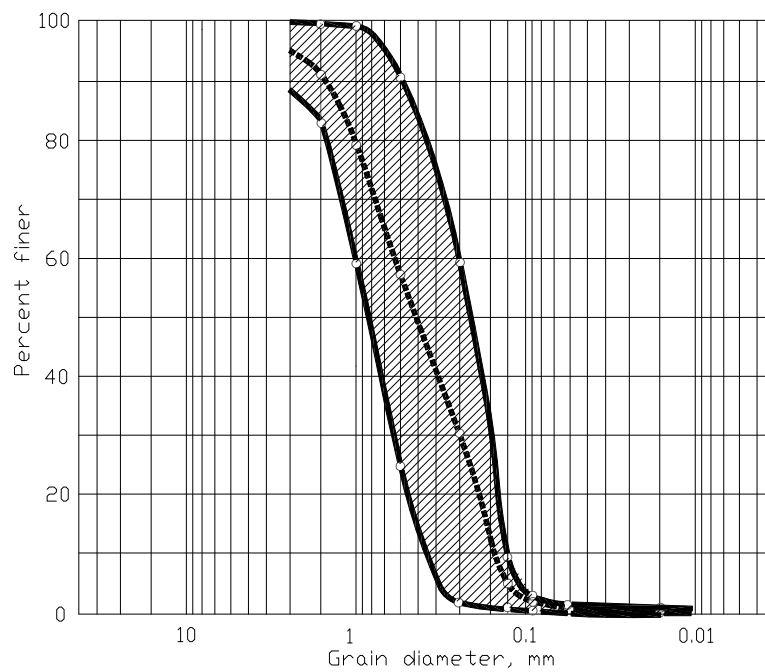


Fig. 5. The reference area or recommended zone as derived from Fig. 4

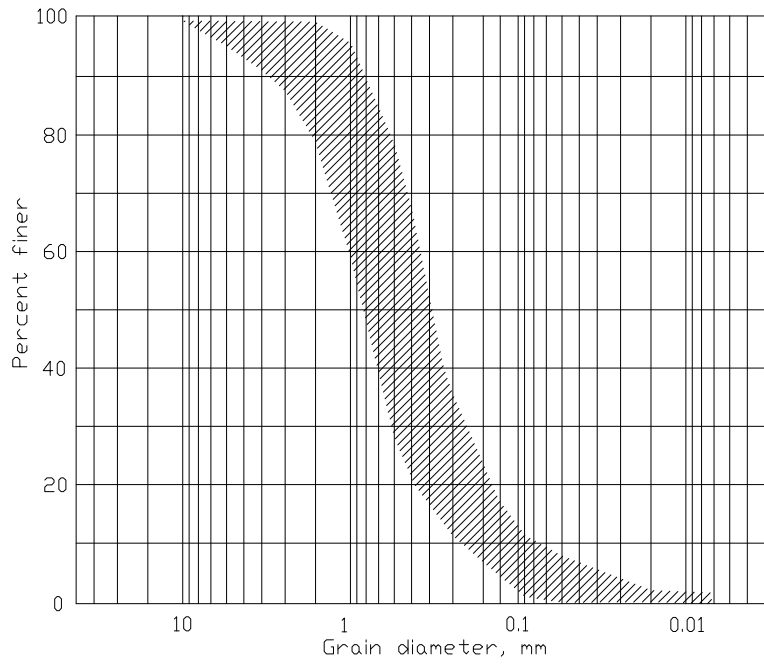


Fig. 6. Grading envelope for external scratch coat

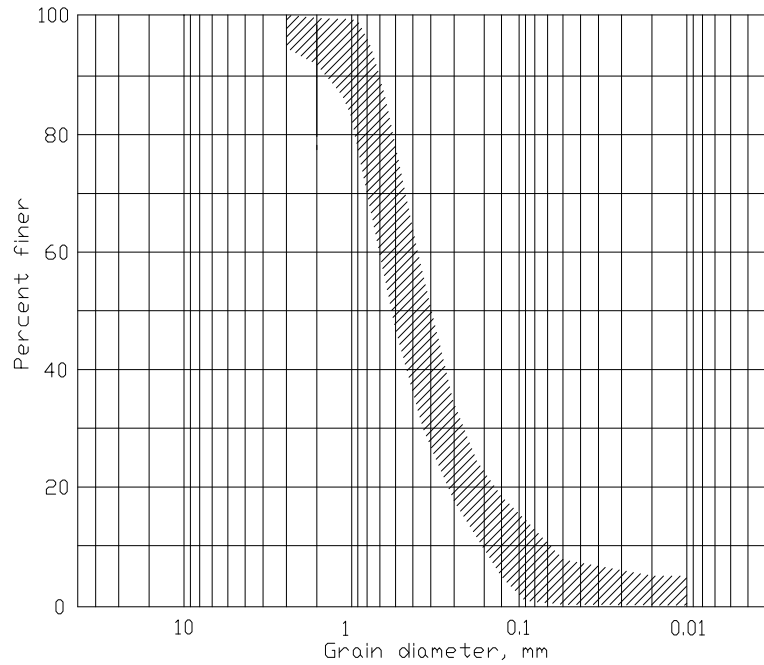


Fig. 7. Grading envelope for external skim coat

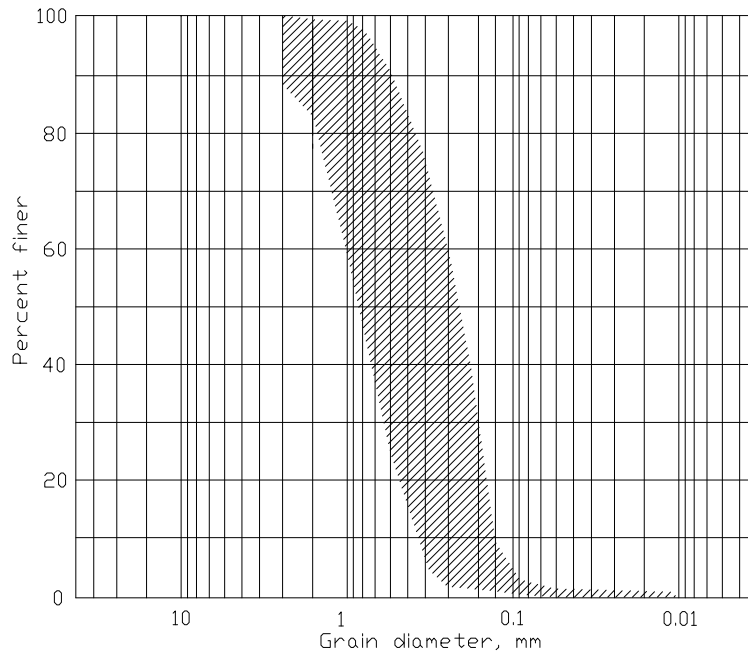


Fig. 8. Grading envelope for internal scratch coat

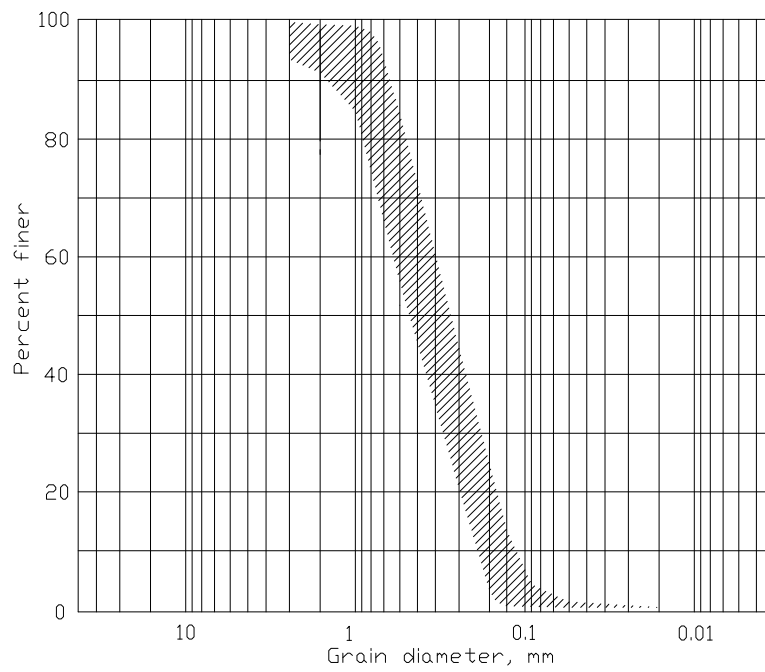


Fig. 9. Grading envelope for internal skim coat

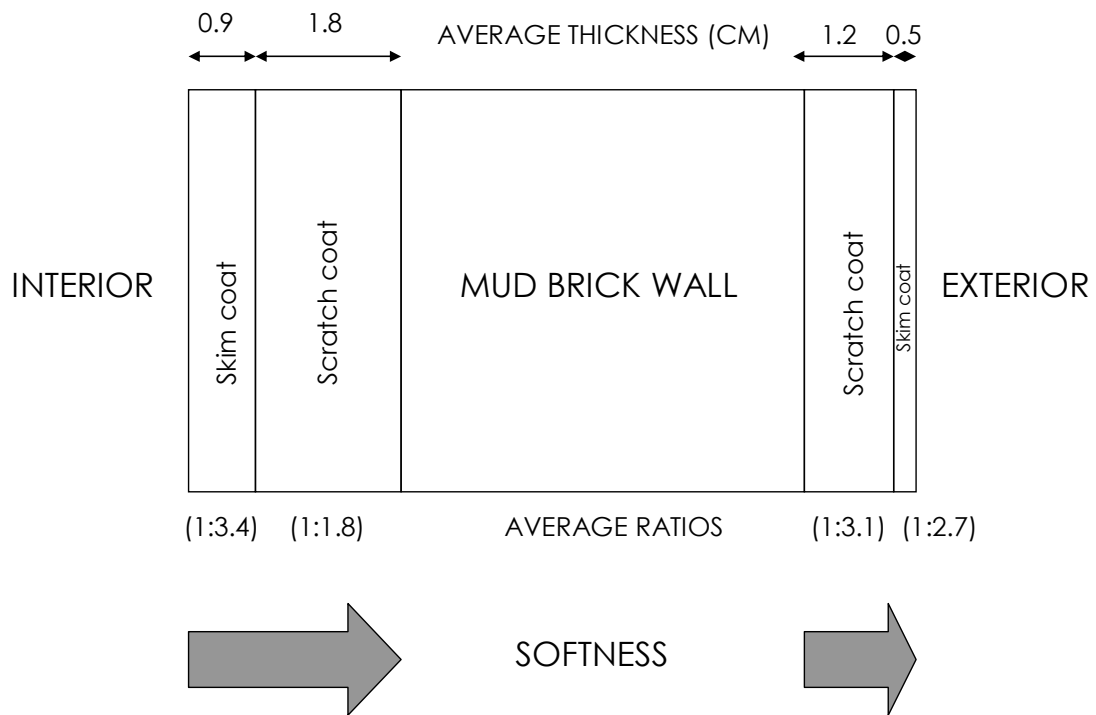


Fig. 10. Drawing showing increase in softness of coats from inside to outside

	Internal scratch coat	Internal skim coat	External scratch coat	External skim coat
Carbonates (%)	35.0	22.3	23.5	26.1
Gravel (%)	4.8	1.9	7.8	2.4
Sand (%)	58.9	74.1	63.2	67.3
Silt and clay (%)	0	0	1.4	0
Ratio lime:aggregate	1:1.2	1:1.3	1:3.1	1:2.7

Table 1. Comparison between experimental results for internal and external coats