Clay Minerals (1998) **33**, 435–442

Grain-size distribution of Italian raw materials for building clay products: a reappraisal of the Winkler diagram

M. DONDI, B. FABBRI AND G. GUARINI

CNR-IRTEC, via Granarolo 64, 48018 Faenza, Italy

(*Received 29 November 1996; revised 25 August 1997*)

ABSTRACT: The grain size of raw materials influences their behaviour during the technological process and affects many properties of building clay products. Over the last few years, brickworks have been technologically updated and grain size requirements have been modified to ensure good behaviour during shaping and drying. Therefore, the reference schemes used to assess the suitability of clays, such as the classic Winkler diagram, should be updated.

For this purpose, the grain-size distribution of 350 clays currently used in ~240 Italian plants was determined by X-ray monitoring of gravity sedimentation. Raw materials are basically represented by silty clays and clayey silts, while bodies present a narrower grain-size range. With reference to the Winkler diagram, most of the Italian bodies fall within the field of 'thin-walled hollow bricks', with no significant differentiation among the various product types.

In order to improve the grain-size characterization of bodies, a new classification scheme for Italian raw materials is proposed, based on three ranges: >10 μm, 2–10 μm and <2 μm, respectively. It allows distinction of specific grain-size features of bodies for (a) facing bricks; (b) roofing tiles; and (c) lightweight blocks, paving bricks and hollow slabs.

The grain size of raw materials influences considerably the behaviour of ceramic bodies during the technological process and also has an effect on many properties of the finished products. This is particularly true with regard to the sources of building clay products, which are only rarely ground and therefore have a grain size which is similar to that of the constituent clays.

The grain-size distribution of raw materials for building clay products influences in particular the behaviour of the material during the shaping and drying processes and affects the microstructure and the mechanical properties of fired materials (Konta, 1980; Kolkmeier, 1991).

Over the last few years, the building clay product plants have been technologically updated and this has partially modified the grain size requirements to ensure good behaviour during the shaping and drying processes. Therefore, the reference schemes, such as the classic Winkler diagram (Winkler, 1954), that are currently used to assess the validity of the grain-size characteristics, should be updated.

Hence, the purpose of this article is to examine the grain-size characteristics of the raw materials used by the Italian structural clay product industry and to verify what differences exist, always in terms of the size distribution of the particles, between the sources exploited to produce different types of structural clay products. This investigation is part of a more extensive programme aimed at characterizing clays and structural clay products used by the Italian sector-related industry (Fabbri & Dondi, 1995a,b).

MATERIALS AND METHODS

About 350 different types of clays used in ~240 plants located throughout Italy were considered (Fig. 1). This sample is representative of the 283 bodies used to fabricate different types of building clay products, as illustrated in Table 1.

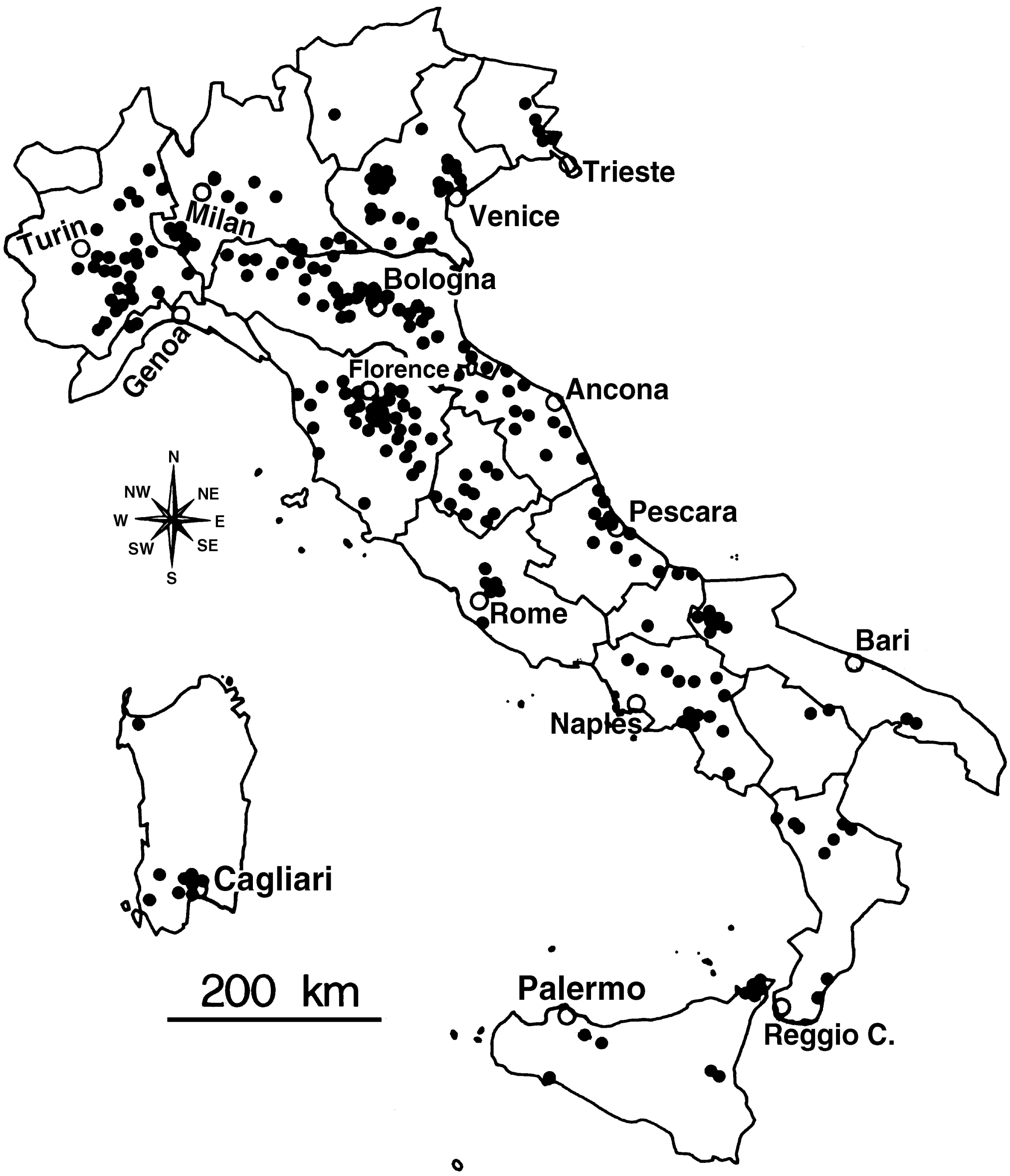

FIG. 1. Location of the Italian brickworks sampled.

The Italian bodies for building clay products are made with a single clay or mixtures of two or three clays, which may also include temper (e.g. sand). The bodies consisting of a single clay represent 40% of the total, while those comprising two to three clays represent 36%. Quartz sand, volcanic rocks (rarely) or ground chamotte are added to the remaining 24%.

A two-phase, grain-size analysis was performed on the clays: by wet sieving, for the >63 μm fraction, and by X-ray monitoring of gravity sedimentation for the fraction ranging between 63 μm and 0.25 μm (using the Micromeritics SediGraph 5000ET). The samples were first dispersed in distilled water by means of stirring and an ultrasonic bath.

TABLE 1. Number of products considered for each typology.

Type of product	Number
Solid bricks and vertically perforated bricks	55
Lightweight blocks	27
Facing bricks	35
Paving bricks	13
Hollow bricks	59
Hollow floor blocks	46
Roofing tiles	30
Hollow slabs, garden vessels, chimney-pots, etc.	18
Total	283

The grain-size curves obtained were used to determine the classification parameters of the clays in the Shepard diagram (Shepard, 1954), and specifically the fractions >63 μm, 4–63 μm and <4 μm. The grain-size distributions of those bodies consisting of two or three clays or clay plus temper were calculated from the grain-size distribution of the single clays. Subsequently, the quantities of the size-fractions considered in the Winkler diagram, i.e. >20 μm, 2–20 μm and <2 μm (Fig. 2) were determined for all the bodies (also those consisting of only one clay).

GRAIN SIZE OF THE CLAYS

Overall, the Italian clays for building clay products have a rather wide range of grain-size distribution. In fact, with reference to Shepard's classification scheme (Shepard, 1954), clays *sensu stricto* as well as silty clays, clayey silts and, in some cases, even sandy clays, sandy silts and loams are currently used (Fig. 3). However, considering the frequency of various types of grain size, the raw materials used to fabricate building clay products are basically represented by silty clays and clayey silts. In fact, there is much less frequent use of loams, while the few cases involving sandy clays and sandy silts refer to plants in which a dry grinding process is performed on the body.

GRAIN SIZE OF THE BODIES

In most cases, the grain sizes of the bodies differ from those of the single clays, given the rather widespread practice of mixing different raw materials; thus, there are fewer grain size differences between the bodies compared to those in the clayey raw materials.

From a statistical point of view, the Italian clay bodies do, however, have a rather scattered distribution of the values of the >20 μm, 2–20 μm and <2 μm size-fractions (Fig. 4). In any case, the situation appears to be similar to a 'normal' type of distribution with a wide range of values. In fact, the percentages of the coarser fraction (>20 μm) are distributed over a range between 4 and 44%, with the maximum frequency around 20–25%. The component between 2 and 20 μm also exhibits a wide range of values (19–59%) which are more concentrated, however, around the more frequent percentages, between ~33 and 47%. The fine portion (<2 μm) fluctuates

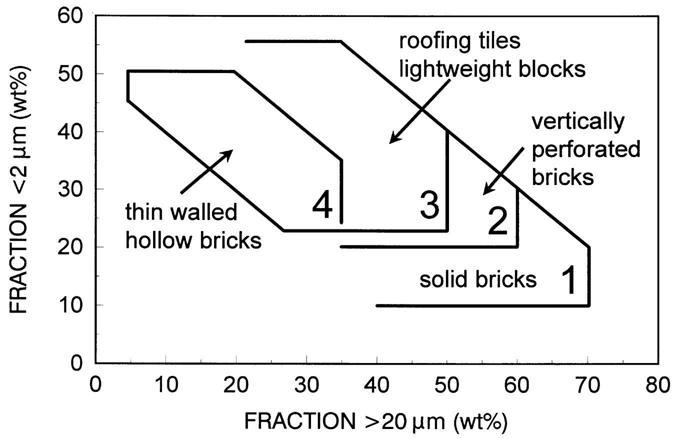

FIG. 2. Winkler diagram (Winkler, 1954) for the technological classification of bodies for structural clay products.

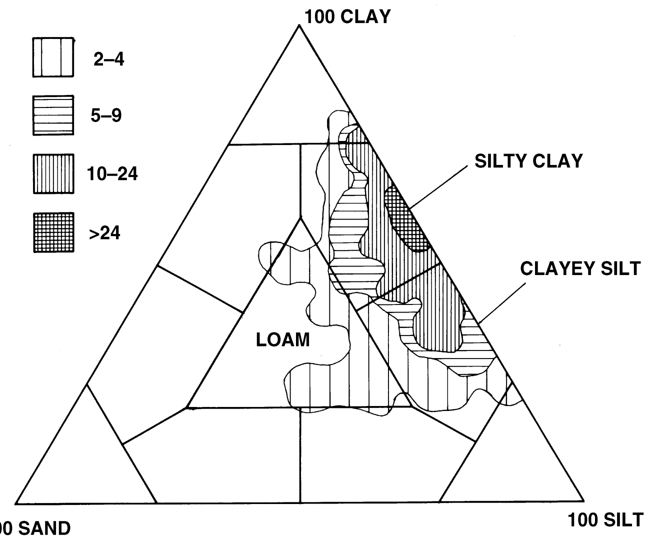

FIG. 3. Distribution of the Italian raw materials in the Shepard diagram (Shepard, 1954). Dashed fields represent the density of points for each percent of the area of the diagram.

between 18 and 57%, with most of the values ranging again between 33 and 47%.

GRAIN SIZE AND TYPE OF PRODUCT

The general trend described above does not change significantly for the different types of building clay products. Figure 5 reports the Winkler diagrams for the eight types of products indicated in Table 1. It is evident that in all cases, the Italian bodies are concentrated within the field of thin-walled hollow bricks or in its immediate vicinity.

There are few exceptions to this general trend and they refer basically to two types of products: paving bricks and facing bricks. In this second case, the bodies with >20 μm fraction values greater than ~35% are distributed in the fields defined by Winkler for solid bricks, vertically perforated bricks and roofing tiles. However, this refers to soft mud rather than extruded bricks, for which a coarse grain size is needed, to enhance workability during shaping and to limit drying shrinkage (van Wijck & Heitink, 1993).

Most of the bodies for paving bricks lie between two fields defined by Winkler for 'thin-walled hollow bricks' and for 'roofing tiles and lightweight blocks', respectively. This case refers to bodies obtained mainly by mixing clays and chamotte followed by dry grinding. The grain-size distribution obtained in this manner, which has less of the 2–20 μm fraction than most of the Italian bodies, is probably due also to the comminution process.

Considering the uniformity of the grain-size distribution of the various types of product, the 283 bodies examined can be used to define an overall frequency scheme of the grain-size distribution of the Italian bodies for structural clay products (Fig. 6). This scheme clearly indicates the trend of a large part of the bodies in question to be located within field 4 or in its vicinity. A smaller number of bodies falls within field 3, while only very few samples are located within the other two Winkler fields. Instead, other samples lie above the fields defined by Winkler, because of their very fine grain size (>55% of the <2 μm fraction).

COMPARISON WITH OTHER TYPES OF PRODUCTION

The Italian situation is perhaps significantly different from that in other countries. Production of building clay materials in Germany (Schmidt-Reinholz, 1986, 1993; Schmidt-Reinholz & Schmidt, 1992) is governed by the grain size and this clearly differentiates the bodies for solid bricks,

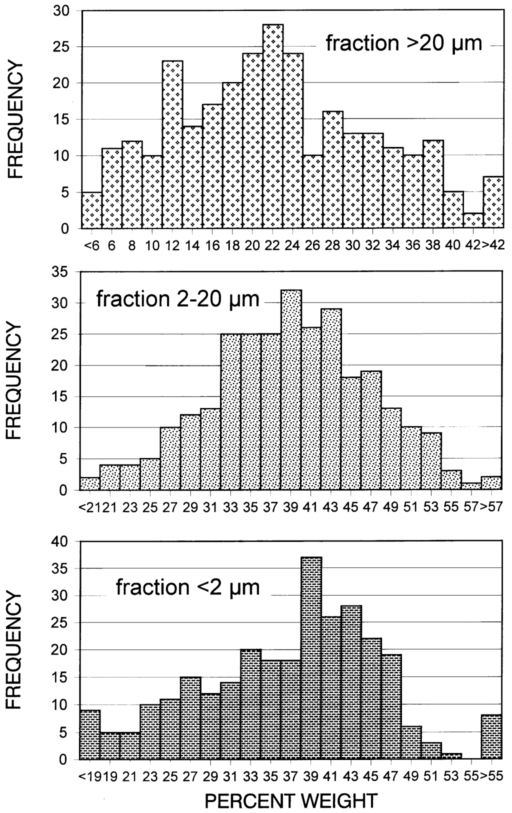

FIG. 4. Frequency distribution of three grain size fractions in the Italian bodies for building clay products.

vertically perforated bricks and roofing tiles, respectively (Fig. 7). This differentiation corresponds rather well to what was originally proposed by Winkler. There are not enough data relating to the hollow products to be statistically significant. In all cases, the German bodies for building clay products are clearly coarser than those currently used in Italy. The grain size of the clays used in Belgium appears to be scattered over a large part of the Winkler diagram (Decleer *et al.*, 1981). In this case, there is not such a marked difference compared to the Italian situation, at least for a part of the Belgian raw materials.

PROPOSED CLASSIFICATION SCHEME

Overall, the Winkler diagram does not make a clear differentiation between the various building clay product types manufactured in Italy. Therefore, an attempt was made to define different grain-size ranges which can improve the characterization of the Italian bodies. Limits were considered which define, within a national framework, three ranges which, on average, are equivalent. These limits are at 10 µm and 2 µm.

Figure 8 illustrates how the bodies used in Italy are characterized, overall, by a great variability of the values of the >10 µm fraction (8–77%) and the <2 µm (12–64%), while the intermediate fraction (2–10 µm) has more uniform contents (10–40%). This overall distribution corresponds to a great extent with the large degree of grain-size variability of the bodies for common bricks, hollow bricks and hollow floor blocks. In fact, these refer to the most widespread Italian products (about two thirds of total production) which are produced in all regions from a wide range of raw materials. Instead, there are some differences relative to the remaining types of structural clay products. (1) The facing bricks are distinguished, based on the shaping techniques: the extruded products tend to be finer than the soft mud bricks. The latter bodies have coarse fraction values mainly >35% and fine fraction percentages almost always <40%. (2) A relatively wide range of grain-size distributions of the bodies for roofing tiles is defined. The products with the highest mechanical and frost resistance values are, however, concentrated in the narrow field represented in Fig. 8. (3) Lightweight blocks, paving bricks and hollow slabs are manufactured from fine grained bodies, with rather uniform grain-size distributions. For all these products there is a convergence of the average value of the ratio between the fractions over 10 µm, 2–10 µm and <2 µm of around 30:30:40.

CONCLUSIONS

The Italian raw materials for building clay products can be classified to a very wide extent as silty clays or clayey silts. The Italian bodies for building clay products comprise both single clay and mixtures of several clay materials; in ~25% of cases, a coarse material is added as a temper (sand).

Most of the bodies tend to fall within the field defined by Winkler for ‘thin-wall hollow bricks’. This scheme cannot be applied rigidly to all Italian manufacture of building clay products. In fact, with such a diagram, an efficient differentiation in terms

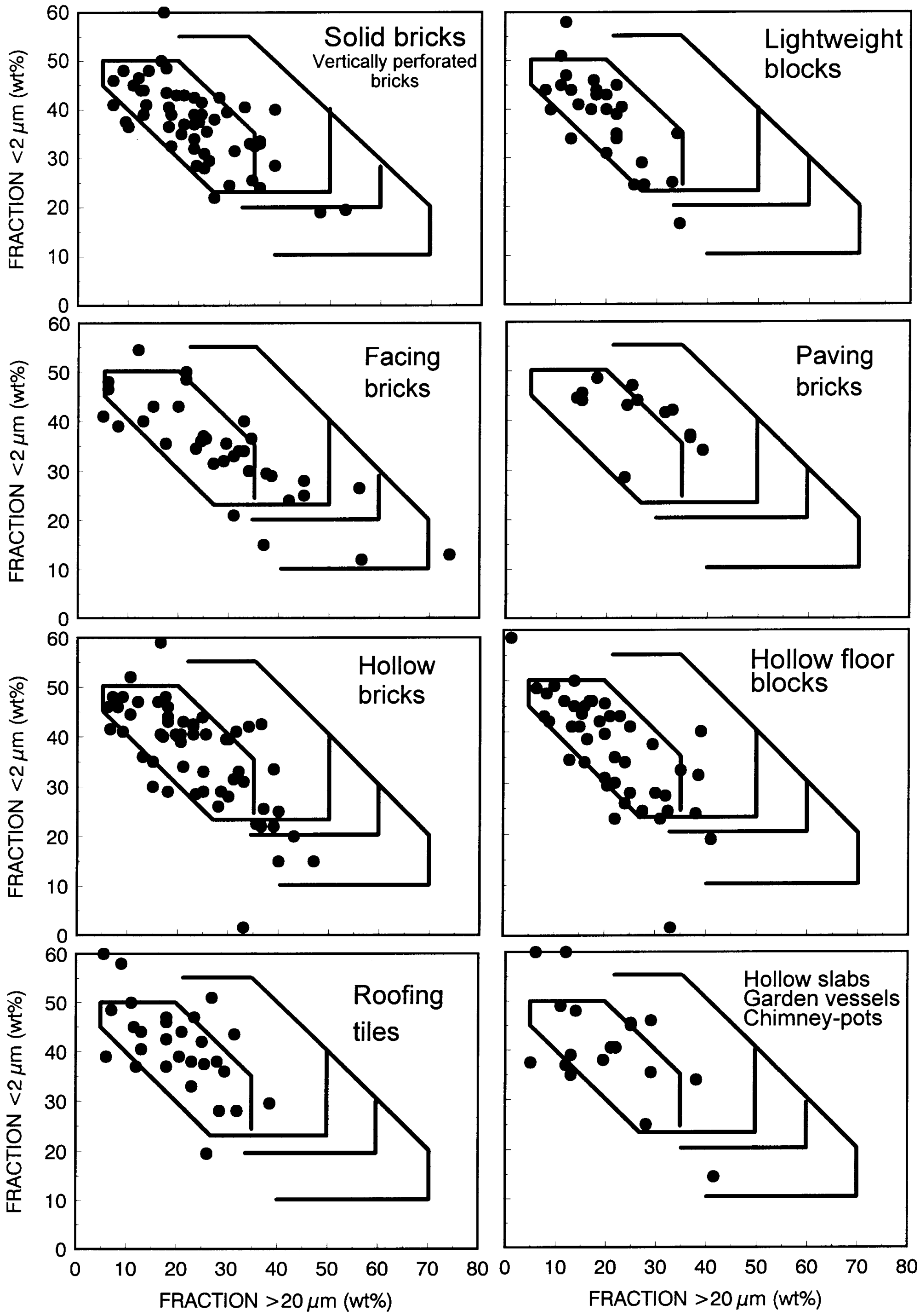

FIG. 5. Distribution in Winkler diagram of Italian bodies for different typologies of building clay products. Fields as in Fig. 2.

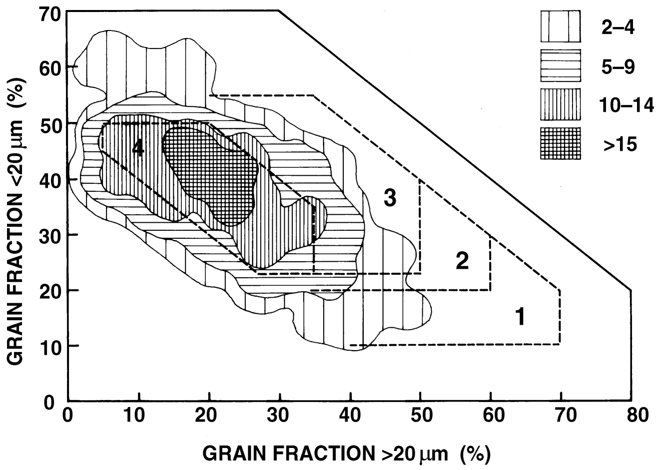

FIG. 6. Frequency distribution of Italian bodies for building clay products in a Winkler diagram. Fields 1, 2, 3 and 4 as in Fig. 2. Dashed areas represent the density of points for each percent of the surface of the diagram.

of grain size cannot be made between the bodies used for the different types of product. At best it is possible to indicate a more appropriate grain-size distribution for facing bricks and for paving bricks with respect to all the other products. These differences are justified by what is often a different method to work these products: dry grinding and soft mud, respectively.

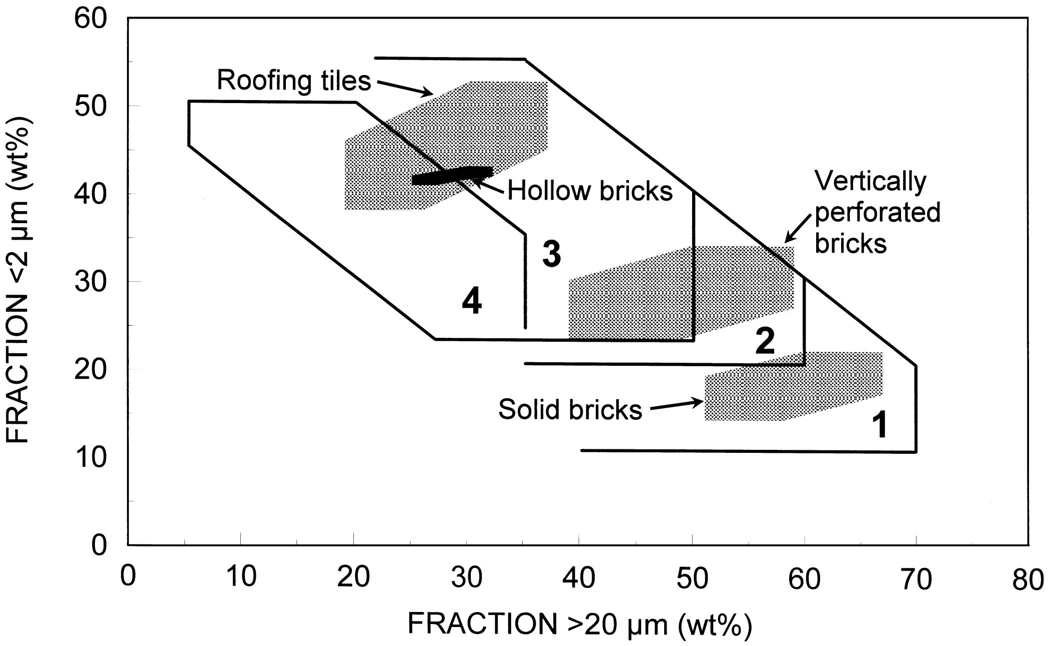

FIG. 7. Typical grain-size distribution for different typologies of German building clay products (Schmidt-Reinholz, 1993) in comparison with Winkler fields (1, 2, 3 and 4 as in Fig. 2).

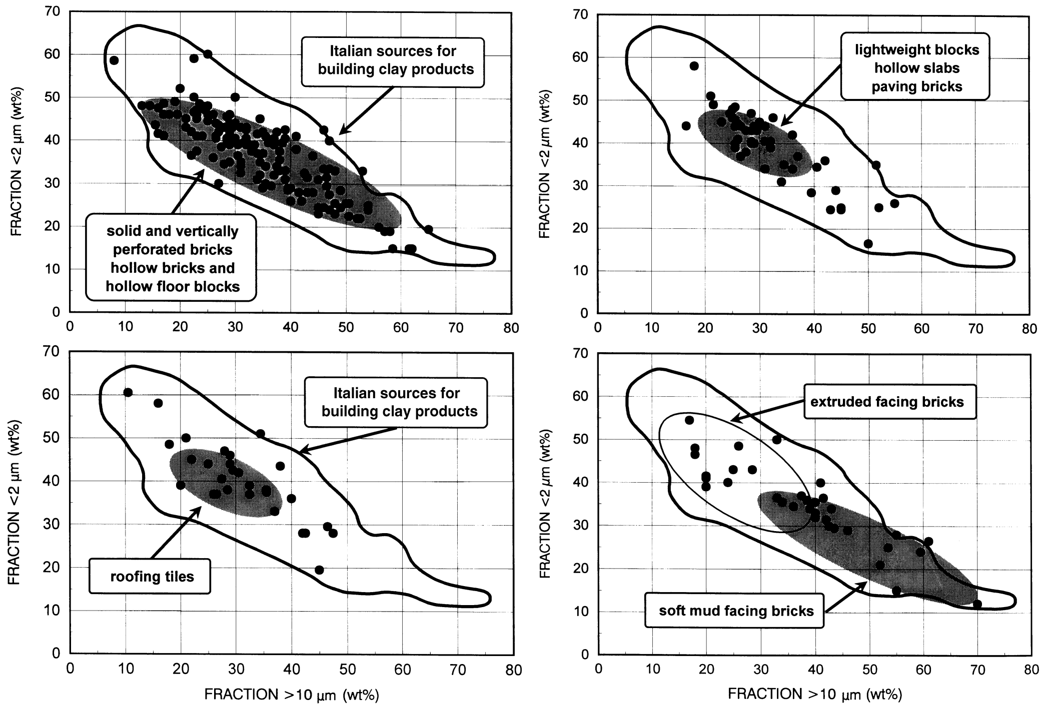

FIG. 8. Classification scheme of grain-size distribution for different types of building clay products.

The Italian bodies are drastically different, in terms of grain size, from those used in Germany. In particular, the Italian bodies are more homogeneous overall and richer in the fine fraction (<2 μm). Therefore, the representation of their grain size is more effective in a ternary diagram in which the fractions considered are <2 μm, 2–10 μm and >10 μm.

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