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(72) **Inventeur/Inventor**:
CANGIANO, STEFANO, IT

(73) **Propriétaire/Owner**:
ITALCEMENTI S.P.A., IT

(74) **Agent**: BERESKIN & PARR LLP/S.E.N.C.R.L.,S.R.L.

(54) **Titre** : BETONS DE PERFORMANCE CONTENANT DE FAIBLES QUANTITES D'ADDITIONS AYANT UNE ACTIVITE HYDRAULIQUE LATENTE
(54) **Title**: PERFORMANCE CONCRETES CONTAINING LOW AMOUNTS OF ADDITIONS WITH LATENT HYDRAULIC ACTIVITY

(57) **Abrégé/Abstract**:

A solid mixture for the preparation of concretes with a mechanical strength after 28 days that is greater than or equal to 110 MPa comprising cement, calcareous aggregates and admixtures characterised by the fact that any additions with latent hydraulic activity are less than 5% by weight compared to the cement.

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(71) Applicant *(for all designated States except US)*: **ITALCEMENTI S.P.A.** [IT/IT]; Via G. Camozzi, 124, I-24121 Bergamo (IT).

(72) Inventor; and
(75) Inventor/Applicant *(for US only)*: **CANGIANO, Stefano** [IT/IT]; Via A. Moro, 73, I-24060 Torre de Roveri (IT).

(74) Agent: GERVASI, Gemma; Notarbartolo & Gervasi, Corso di Porta Vittoria, 9, I-20122 Milano (IT).

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(54) Title: HIGH PERFORMANCE CONCRETES THAT DO NOT CONTAIN ADDITIONS WITH LATENT HYDRAULIC ACTIVITY

(57) Abstract: A solid mixture for the preparation of concretes with a mechanical strength after 28 days that is greater than or equal to 110 MPa comprising cement, calcareous aggregates and admixtures characterised by the fact that any additions with latent hydraulic activity are less than 5% by weight compared to the cement.

PERFORMANCE CONCRETES CONTAINING LOW AMOUNTS OF ADDITIONS WITH LATENT HYDRAULIC ACTIVITY

Field of invention

The present invention relates to the making of high performance concrete that can be obtained without significant quantities of additional material with latent hydraulic activity, in particular silica fume.

Prior art

Before describing the present invention in detail, it is appropriate to define the meaning of some terms and to refer to the state of the art that can be deduced from technical and patent literature on the subject.

The expression "high performance" currently refers to a relatively wide range of usage properties for cementitious mixtures and in particular the rheological and mechanical performances.

With regards to the rheological performance, a high performance concrete is usually required to be at least thixotropic or, preferably, self-compacting.

With regards to mechanical performance, the expression "high performance" refers to a wide range of mechanical strengths. According to Aitcin (High performance concrete (E& FN SPON – Modern Concrete Technology 5 – page 163 Ed. 1998) these types of concrete can be divided into five different categories, each of which is defined by compressive strength values that correspond to those that can be considered to be a technological range in the present state of the art.

Table I Classification of high performance concretes as proposed by Aitcin

Compressive strength MPa	50	75	100	125	150
Category of high performance concrete	I	II	III	IV	V

Even though there is currently no universally accepted definition of high performance concrete, a study of literature allows us to state that the essential property that qualifies a concrete as being high performance is its mechanical compressive strength that is, however, measured later than or at 28 days, while the other usage properties, which also contribute to classifying concrete at a high performance material, are not considered to be essential as they are additional specific requirements.

Concretes having compressive strength that is higher than 100 MPa are commercially available. Types of concrete with mechanical properties that are much higher than those foreseen by the current design codes are also currently available (e.g. Ductal® – BSI see WO99/28267).

It is well-known that in order to obtain high strength concrete it is necessary to adopt a reduced water/binder ratio (binder here is intended as Portland cement and any other suitable material) and a quantity of binder that is usually higher than the one required for normal level strength concretes (4, 5, 6, 7, 8, 9);

4 - Zeghib, R. et al "Study and formulation of high performance concrete with ultrafine admixtures" Fifth ACI/CANMET Conference on superplasticisers and Chemical admixtures in Concrete.

Supplementary papers, Rome 1997 pages 286-293;

5 – Lang, E et al. "Use of Blast Furnace slag cement with high slag content for high performance concrete" – 4th International symposium on Utilisation of high Performance Concrete, Paris 1996, pages 213-222;

6 – Novokshchenov, V. "Factors Controlling the compressive strength of silica fume concrete in the range of 100-150 MPa" Magazine of Concrete Research, 1992, N. 158, pages 53-61;

7 – Shah, S.P. et al. "High Performance Concrete: Properties and applications" 1994, Mc Graw Hill, Inc, London 403 page;

8 – Gjorv, O. E. "High Strength Concrete" In "Advance in Concrete Technology" Ed. CANMET, Edition Malhotra, 1994 pages 19-82;

9 – De Larrard "Formulation et proprietes des betons a tres hautes performances. Rapport de recherche Du Laboratoire Central de Ponts et Chaussées, Paris N. 149, 1988, 350 page

The current European regulations on concrete (EN 206) permit the addition of ultrafine materials to concrete with the aim of obtaining or improving some properties. The EN 206 regulation considers two types of addition:

- Almost inert addition (**type I**) one of which may be limestone;
- Pozzolan type or latent hydraulic activity additions (**type II**) are fly ash which is compliant with the EN 450 regulation and silica fume compliant with the p.r. EN 13263:1998.

It is known that high performance concretes belonging to categories I and II with a compressive strength up to 100 MPa as set out in the table above can be produced from a large variety of cementitious systems such as:

- Pure Portland cement;
- Portland cement and Fly ash;
- Portland cement and silica fume;
- Portland cement, slag and silica fume;

According to Aitcin (1999, pages 190-191), based on data taken from literature, it appears that almost all high performance concretes in category III (from 100 to 125 MPa) contain silica fume, except for very few types of concrete that are produced using Portland cement, whose strength values fall into a area below this category.

Again according to Aitcin (E& FN SPON – Modern Concrete Technology 5 – pages 190-191 Ed. 1999) all the high performance concretes that currently belong to categories IV and V, have all been produced using silica fume.

Several studies have looked at the effects of silica fume on the hydration reactions of the cementitious systems. Below there is brief summary of the main results of these studies. It is known that the action of silica fume reveals itself as both a pozzolan addition and as a filler. Silica fume acting as a granular filler between the cement particles can be explained by its extremely reduced dimensions (from 30 to 100 times smaller than that of Portland cement). It has been established that it is possible to replace silica fume with Carbon black and obtain similar strengths (Derweiler and Mehta – 1989 – "Chemical and Physical effect of silica fume on the mechanical behaviour of concrete" ACI Material Journal Vol. 86 n. 6 pp 609-614). The silica fume particles can also act as nucleation sites and at the same time improve the homogeneity and the fineness of the hydration products (Nehdi, 1995, "The microfiller effect in high performance concrete" Research proposal, department of civil engineering, University of British Columbia.)

According to Cheng Yi and Feldman (1985 Cement and Concrete Research vol. 4 pages 585-592) silica fume speeds up the cement's hydration reaction by encouraging the creation of nucleation sites for $Ca(OH)_2$ crystals even during the initial minutes after the start of the hydration reaction. Metha (1987-Proc. Int. Workshop on condensed silica fume in concrete, Ed. V.M. Malhotra, Montreal.)

too maintains that the silica fume particles could act as nucleation sites for the precipitation of Portland cement and that the formation of several small-sized crystals in place of a few large ones could improve the mechanical properties of the cementitious paste.

In contrast to the advantages coming from the use of such an addition material, however, it is necessary to point out that the silica fume addition in some cases seems to cause an increase in shrinkage during the plastic phase and can lead to significant phenomena of micro – flaws /SP 186-39 page 671 (E& FN SPON – Modern Concrete Technology 5 – 4 page 191 Ed. 1998) e (S. Rols et al. "Influence of Ultra Fine Particle Type on Properties of Very – High strength Concrete ACI SP 186 pages 671-685- Proceedings of Second CANMET/ACI International Conference, RS, Brazil, 1999). It must also be pointed out that the use of silica fume is particularly costly. Again according to Aitcin, this explains why concrete manufacturers tend to avoid using silica fume for the production of high performance concretes that belong to categories I and II. The cost of a type of concrete can almost double when passing from a 90 MPa concrete to a 100 MPa one; concrete with a design strength of 90 MPa can actually easily be produced without silica fume, whereas to currently produce a 100 MPa concrete, about 10% of the mixture must be made up of silica fume. (E& FN SPON – Modern Concrete Technology 5 – page 163 Ed. 1998).

While analysing the performances of high-performance cementitious materials, it is necessary to highlight the increase in mechanical strength that arises from the presence of steel micro-fibres. It is appropriate to point out that a correct comparison between the performances of cementitious matrixes with different compositions must be made by materials without fibre reinforcement. Finally, the following is deduced from literature:

- no cementitious matrix, seasoned in water or in a cloud chamber (20°C, 95% U.R) is capable of achieving such strengths after 28 days that it can be included in category V of table I;
- the workability data are not usually included and after examination of literature, however, no published works have been found that refer to concretes (cementitious matrixes) in category IV with self-compacting properties.

- No data is available on the development of strength at the first deadlines (24 and 48 hours).

As far as the calcareous filler is concerned, it has long been considered to be inert. Although it cannot be considered as a pozzolanic addition material, many studies have shown that it has a considerable mid and long-term reactivity. S. Sprung, E. Siebel "..." Zement Kalk Gibs 1991, N. 1, pages 1-11 put forward the theory that in addition to its main role as a matrix filler, the calcareous filler may also present a certain chemical reactivity towards the aluminate which allows the formation of calcium aluminates to take place. Ramachandran et al. (Ramachandran et al. In "Durability of Buildings Materials", 4 1986) observed that adding $CaCO_3$ to C_3S (tricalcium silicate) accelerates hydration. They also discovered that cement hydration is faster due to the calcareous filler. In the cement mixture, $CaCO_3$ would give rise to calcium aluminates that would be incorporated in phases C_3S and C_3A (tricalcium aluminate) during hydration. S.P. JIANG et al. ("Effect of fillers (Fine particles) on the Kinetics of Cement Hydration 3rd Beijing International Symposium on Cement and Concrete, 1993,3) also showed that the formation of calcium aluminates is advantageous as it would improve strength and accelerate the hydration process. Jiang et al. (S.P. Jiang et al. 9th International Congress of Cem. Chem. New Delhi, 1992) maintained that calcareous filler acts on the kinetics of cement hydration. According to these authors, rather than being attributed to the description above, the acceleration of hydration may instead be attributed to a multiplication of the inter-particle contacts effect and to the nature of these contacts on the calcareous filler surface.

Escadeillas (G. Escadeillas, Les ciments aux fillers calcaires: Contribution a leur optimisation par l'etude des propietés mecaniques et physiques des betons fillerisées, Ph Thesis, Université P Sabatier (1988) 143 p.) observed that in the first few hours of hydration, the heat release from cement containing calcareous filler is greater than that coming from cement without filler and this is even more true the finer the calcareous filler. This is probably due to the acceleration in the hydration of the C_3S.

With regards to high performance from a rheological point of view, the importance that self-compacting concrete is gaining is well known.

Self-compacting concrete (SCC) is a special concrete that can run into the formworks just by the effect of its own weight and flow around any obstacles such as reinforcement bars without stopping and without causing any separation phenomena of its elements. Its rheological properties must be preserved until the setting and hardening process begins.

According to the AFGC (Association Française de Genie Civil) self-compacting concretes must meet the following requirements when fresh:

a) The spreading values of the Slump Flows (slump cone) must usually fall within the field 60 ÷ 75 cm (with no visible segregation at the end of the test, i.e. no lactim aureola along the outer perimeter and no concentration in the centre);

b) The filling ratio of the equipment named L-Box must be greater than 80%;

c) the concrete must not give rise to segregation and must present limited sweating.

At the current state of knowledge, no high performance concretes have been produces without silica fume in category IV or V with self-compacting properties.

M. Sari et al. (Cem. Conc. Research n. 29 (1999), for example, obtained a self-compacting high performance concrete with a slump flow of 61.5 cm. The mixtures considered contained 30 kg/m^3 of silica fume and presented a 70 MPa strength after 28 days.

From an analysis of the bibliography reviewed, no data or information was found on the possibility of preparing high strength concrete (at least in category III) without silica fume and with the rheological properties that are typical of a self-compacting concrete.

Summary

The Applicant has surprisingly found a solid mixture for the preparation of concretes with a mechanical strength after 28 days that is greater than or equal to 110 MPa comprising cement, such as cement that is compliant to the European regulation 197-1, calcareous aggregates and admixtures characterised by the fact that any additions with latent hydraulic activity are less than 5% by weight compared to the cement.

Description of the figures

Figure 1 shows the reference curves corresponding to the equations [1] wherein A=0.75 and [2]; they are compared with the other curves normally used as reference curves for the system: aggregate + cement, i.e. more specifically the well-known Fuller and Bolomey curves are shown. With regards to the Bolomey curve, the two curves whose parameter A_B depending on the aggregate form, takes on the two limit values of 8 and 14 have been considered.

The variance between the curves of the prior art and the curves of the invention can clearly be seen.

Figure 2 shows the experimental curves of the particle-size distribution of the three fractions of calcareous aggregate al (fraction 0, fraction 1 and fraction 2).

Figure 3 shows the experimental curves of the particle-size distribution of the five fractions of calcareous aggregate al (fraction A, fraction B, fraction C, fraction D and fraction E).

Figure 4 shows the experimental curves of the particle-size distribution of the sole fraction of comparative calcareous aggregate a2. As can be seen, the curve is near to the Fuller curve.

Figure 5 shows the experimental curves of the particle-size distribution of the three commercial silica-calcareous aggregate fractions b (Sataf 113, Sataf 103, Sataf 117 R respectively).

Figure 6 shows the cumulative distribution curve of the cement in relation to its maximum content in the solid mixture (21%); the reference (according to equation [2]) and actual particle-size distribution curves of the solid mixture of the invention ~~CO are also shown. It can be seen that the distribution curve joins with the~~ cement curve without causing particularities, it also has a flex point of x=0.315 mm.

Figure 7 shows the particle-size distribution of the above-mentioned solid CO1 mixture, the particle-size distribution curve according to equation [1] wherein A=0.822 compared with the other curves normally used as reference curves for the system: aggregate + cement, i.e. more specifically the well-known Fuller and Bolomey curves are shown. With regards to the Bolomey curve, parameter A_B takes on the limit value 14, has been considered.

Figure 8 describes the particle-size distribution curve of the solid mixture C1 compared to the reference curve corresponding to the equation [1] wherein A=0.75.

If one looks at figure 8, the considerable variance from the reference curve Eq.[1] wherein A=0.75, in the upper region of the typical particle-size field of CEM 52.5R, can clearly be seen.

Figure 9 shows the particle-size distribution curve of the solid mixture C2 for comparison.. Figure 9 shows that the mixture made from CEM 52.5R and calcareous aggregate has a considerable variance from the reference curve Eq.[2], and tends to resemble the Bolomey curve by $A_B = 14$.

Figure 10 shows the behaviour of the ICO-A mix and ICO1-A mix characterised by a much more limited shrinkage during the plastic phase than that found in the quartz aggregate and vitreous silica based mix IC3-A.

Detailed description of the invention

Object of the present invention

The object of the present invention is to perfect a concrete formula with the following characteristics:

1) absence of significant quantities of type II additions (for example silica fume)
2) a mechanical strength after 28 days that is greater than 110 MPa and/or a development of compressive strength to the extent that it ensures the values contained in table II below.

Table II Performance requirements required for the development of mechanical strength.

Deadline [days]	1	2	28
Rc [MPa]	≥50	≥80	≥110

The expression: "without significant quantities of additions with a latent hydraulic activity" is intended to mean that these additions must be less than 5% by weight compared to the cement, and preferably less than 2%.

A further object of the present invention is to perfect a formula of a self-compacting concrete satisfying the characteristics as set out in points a), b) and c) described above.

Another object of the invention is to obtain fibre-reinforced concretes with rapid hardening, without significant quantities of type II additions, for example silica fume.

It has been surprisingly found out that it is possible to achieve the aims described above, to the contrary of the bias expressed by the prior art, by using an optimal particle-size composition of the solid cement mixture and calcareous aggregate. In particular, it was found that if such a particle-size composition is used that the passing percentage composition according to the diameter of the particles follows that of the curve constructed according to table III below, it is possible to obtain a high performance concrete with development of mechanical strength in time as indicated in Table II, without significant quantities of pozzolanic type additions.

TABLE III

Diameter (mm)	Passing %
0.002	5-12
0.005	10-13
0.01	15-20
0.1	30-40
0.2	40-60
0.4	50-75
0.7	60-85
1	70-90
2	85-95

The particle-size composition of the solid mixture can be more appropriately described by the curve that is represented by the equation:

$$P\% = \frac{1}{A + \dfrac{(1-A)}{\sqrt{x/D_{max}}}} .100 \qquad (\text{for } 0 < x \leq D_{max}) \quad [1]$$

Where:

P%= cumulative passing;

x= diameter of the solid particles in mm;

A = experimental parameter which has the following values: 0.75 or 0.822;

D_{max}= maximum diameter of aggregate in mm;

Another possible curve is as follows:

$$P\% = 1 - e^{\left(\frac{-x}{C}\right)^{D}} . 100 \qquad [2]$$

Where:

P%= cumulative passing;

x= diameter of the solid particles in mm;

C, D= experimental parameters (C= 0.315 [mm], D= 0.486);

The value C=0.315 mm indicates the diameter below which 63.2% of the solid mixture passes.

Figure 1 contains the reference curves that correspond to the equations [1] and [2]; they are compared with the other curves normally used as reference curves for the system: aggregate + cement; more specifically, the well-known Fuller and Bolomey curves have been included, which respectively have the equation:

$$P\% = 100 \sqrt{x/D_{MAX}} \qquad [3]$$

Where:

P%= cumulative passing;

x= diameter in mm;

D_{max}= maximum dimension of aggregate;

$$P\% = [A_B + (100 - A_B)\sqrt{x/D_{MAX}}] \qquad [4]$$

Where:

P%= cumulative passing;

x= diameter in mm;

D_{max}= maximum dimension of aggregate;

A_B= Bolomey parameter (typically takes on the two limit values of 8 and 14 depending on the aggregate shape)

Some of the preferred embodiments according to the present invention are as follows:

- A solid mixture for the preparation of concrete with a mechanical strength after 28 days that is greater than or equal to 110 MPa , comprising cement, such as cement that is compliant with the European regulation 197-1, calcareous aggregates and admixtures, characterised by the fact that the possible latent hydraulic activity additions are less than 5% in weight compared to the cement;
- A solid mixture for the preparation of concrete with a mechanical strength after 28 days that is greater than or equal to 110 MPa , comprising cement, calcareous aggregates and admixtures, characterised by the fact that the possible latent hydraulic activity additions are less than 2% in weight compared to the cement.
- A solid mixture for the preparation of concrete that over time has the following development of mechanical strength: after one day: ≥ 50 MPa; after 2 days: ≥ 80 MPa; after 28 days: ≥ 110 MPa; and comprising cement, such as cement that is compliant with the European regulations 197-1, calcareous aggregates and admixtures, characterised by the fact that any latent hydraulic activity additions are less than 5% in weight compared to the cement.
- A solid mixture for the preparation of concrete that over time has the following development of strengths: After one day: ≥ 50 MPa; after 2 days: ≥ 80 MPa; after 28 days: ≥ 110 MPa; and comprising cement, such as cement that is compliant with the European regulations 197-1, calcareous aggregates and admixtures, characterised by the fact that any latent hydraulic activity additions are less than 2% in weight compared to the cement.

According to the present invention cement and hydraulic binder are synonyms.

As cements to prepare the solid mixture according to the present invention, all cements or hydraulic binder in general, and more specifically those according to the EN 197-1 regulation, can be used.

More over according to the present invention as a further preferred embodiment the cement in the solid mixture is CEM I 52.5 R or CEM III A 52.5 R, with a slag content of 40% by weight compared to the clinker. In general the cement is present from 25% to 50% by weight, preferably from 30% to 35% by weight compared to the total solid mixture. Furthermore in a preferred embodiment of the present invention the calcareous aggregates are crushed calcareous aggregates with a $CaCO_3$ content that is greater than or equal to 95% by weight compared to the total weight of the aggregate.

The solid mixture according to the present invention has the calcareous aggregates with a D_{Max} (maximum Diameter) from 2 mm to 12 mm, preferably from 4 to 8 mm or from 8 to 12 mm, most preferably of 9.5 mm.

As a further preferred embodiment the admixtures in the solid mixture are either acrylic or naphthalenesulfonate admixtures, in particular the acrylic admixtures are present from 0.4% to 1.2% by weight, preferably from 0.5% to 0.8% by weight, compared to the weight of the cement; the naphthalenesulfonate admixtures are present from 1.9% to 2.5% by weight compared to the weight of the cement. As a further preferred embodiments the solid mixture, according to the present invention, it further comprises metal fibres.

Further preferred embodiments according to the solid mixture which is the common inventive concept of the present invention are as follows:

- A cementitious mix for the preparation of concrete with a mechanical strength after 28 days that is greater than or equal to 110 MPa comprising a solid mixture according to the present invention, characterised by the fact that any additions with latent hydraulic activity are less than 5% by weight compared to the cement and that have a water/cement ratio from 0.2 to 0.3, preferably from 0.24 to 0.26.
- A concrete with a mechanical strength after 28 days that is greater than or equal to 110 MPa comprising a solid mixture according to the present invention, characterised by the fact that any additions with latent hydraulic

activity are less than 5% by weight, preferably less than 2% by weight, compared to the cement.

A concrete with a mechanical compressive strength after 28 days that is greater than or equal to 110 MPa comprising a solid mixture for the preparation of concrete with a mechanical compressive strength after 28 days that is greater than or equal to 110 MPa, comprising cement, calcareous aggregates and admixture, and Pozzolan or fly ash type II additions according to the EN 206 regulation in amount less than 5% by weight of the cement, wherein the particle-size distribution of the mixture is shown on the graph of the cumulative percentage of passing material according to the size of the particles in mm, from a curve that substantially corresponds to the values shown in the following table:

Diameter (mm)	Undersize %
0.002	5 – 12
0.005	10 – 13
0.01	15 – 20
0.1	30 – 40
0.2	40 – 60
0.4	50 – 75
0.7	60 – 85
1	70 – 90
2	85 - 95

as characterised by the fact that any additions with latent hydraulic activity are compared to the cement.

A solid mixture based on cement and aggregate mainly of calcareous type, containing an addition with latent hydraulic activity in quantities less than 5 % by weight, characterised by the fact that the particle-size distribution of the mixture is shown on the graph of the cumulative percentage of passing material according to the size of the particles in mm, from a curve that substantially corresponds to the curve defined by the equation:

$$P\% = \frac{1}{A + \frac{(1-A)}{\sqrt{x/D_{MAX}}}} \cdot 100 \qquad (\text{for } 0 < x \leq D_{max}) \quad [1]$$

Where:

P% = cumulative passing;

x= diameter of the solid particles (mm);

A= experimental parameter (=0.75) ;

D_{max}= maximum diameter of aggregate (mm);

or the above said solid mixture based on cement and aggregate of mainly calcareous type, wherein in the equation [1] the experimental parameter A is 0.822.

- A solid mixture based on cement and aggregate of mainly calcareous type, containing an addition with latent hydraulic activity in quantities less than 5 % by weight, characterised by the fact that the particle-size distribution of the mixture is shown on the graph of the cumulative percentage of passing material according to the size of the particles in mm, from a curve that substantially corresponds to the values shown in table III.

Preferably, the aggregate of mainly calcareous type is limestone.

The following examples are conveyed by way of indication, not of limitation, of the present invention.

Examples

Experimental part

The materials used for the experiment were:

Cement

A CEM cement type I category 52.5R and a CEM cement type III, 52.5R were used, both compliant with the regulation EN 197-1 and with a Blaine fineness of 4900 cm^2/g.

Admixtures

Commercial acrylic admixtures (Superflux® AC 2003) and naphthalenesulfonate admixtures (Superflux NF®), were used.

Mixing water

~~A type of mixing water was used that is compliant with pr EN 1008:1997.~~

Aggregates

The following aggregates were used:

a) type a1 and a2 crushed limestone;
b) Tondo di fiume of a silica-calcareous nature;
c) Pure crushed quartzite;

a1 - Crushed limestone aggregate

The limestone used was characterised by a compact crystalline structure, coming from the Rezzato (BS) quarry, and with a chemical composition as indicated in table IV, and the same table shows the average value of water absorption. The cumulative particle-size distribution, i.e. the particle-size distributions of the three fractions (fraction 0, fraction1 and fraction 3) or the particle-size distributions of the five fractions (fraction A, fraction B, fraction C, fraction D, fraction E) are shown in figure 2 and figure 3 respectively.

Table IV Chemical composition and average value of water absorption of the a1 type limestone aggregate

$CaCO_3$	98.61 %
Mg CO_3	0.87 %
SiO_2	0.13 %
Al_2O_3	0.01 %
Fe_2O_3	0.03 %
Na_2O	0.12 %
K_2O	0.07 %
T.O.C.[1]	0.02 %
Absorption H_2O	0.28 %

[1] T.O.C. stands for: Total Organic Carbon

a2 - Crushed limestone aggregate

For comparison purposes an a2 crushed limestone aggregate from the Halips quarry (Greece) was used, that is characterised by the fact that is was supplied in a single size with a maximum diameter of 4.5 mm (substantially the same as that of the fraction 2 of the a1 limestone aggregate). The cumulative particle-size distribution is shown in figure 4.

If we examine the afore-mentioned figure, it is possible to observe that this distribution is close to that of the well-known particle-size curve Fuller (Il calcestruzzo- Materiali e tecnologia di Vito Alunno Rossetti- Mc Graw-Hill 1995 pp 103-104).

Table V contains the chemical composition and the average value of water absorption for the aggregate a2.

Table V Chemical composition and average value of water absorption of the limestone aggregate "Halips"

$CaCO_3$	97.5%
$Mg\ CO_3$	0.87%
SiO_2	0.30%
Al_2O_3	0.14%
Fe_2O_3	0.12%
Na_2O	<0.08%
K_2O	<0.04%
T.O.C.[1]	0.025%
Absorption H_2O	0.18%

[1] T.O.C. stands for: Total Organic Carbon

On comparing the data contained in table IV and the data contained in table V, it can reasonably be stated that the two calcareous aggregates a1 and a2 have the same chemical composition and water absorption characteristics.

<u>b - Silica-calcareous tondo di fiume</u>

For comparison reasons, an aggregate of river origin <u>b</u> was used with the composition shown in table VI, while the cumulative particle-size distribution of the three commercial particle-size fractions (Sataf 113, Sataf 103, and Sataf 117R respectively) is shown in figure 5.

Table VI Chemical composition and water absorption of the silica-calcareous aggregate

$CaCO_3$	9.20 %
$Mg\ CO_3$	15.86 %
SiO_2	71.08 %
Al_2O_3	6.46 %
Fe_2O_3	3.12 %
Na_2O	1.05 %
K_2O	1.23 %
T.O.C.[1]	-
Absorption. H_2O	0.33 %

[1] T.O.C. stands for: Total Organic Carbon

c - Pure crushed quartzite

For comparison purposes pure crushed quartzite was used as an aggregate, according to the patent WO 99/28267.

Fibres

Berkert ON 13 straight steel fibres were used

Mix composition

The concrete mix composition according to the invention comprises:

- from 25% to 50% by weight and preferably 30÷33% of type 1 CEM 52.5R cement;
- silica fume less than 5% by weight and preferably less than 2 %, compared to the cement weight,
- crushed limestone aggregate with D_{max} (maximum diameter) from 2 mm to 12 mm, preferably with D_{max} (maximum diameter) from 4 mm to 8 mm, also preferably with D_{max} (maximum diameter) from 8 mm to 12 mm, most preferably with a D_{max} (maximum diameter) of 9.5 mm in quantities as a complement to 100 compared to the cement.
- acrylic-based super fluidifying agent from 0.4% to 1.2% by weight (preferably 0.5 – 0.8%) or naphthalenesulfonate-based from 1.9 to 2.5% by weight expressed as a dry substance on the cement
- water/cement ratio: 0,2-0,3 (preferably 0.24-0.26).

~~The above-stated percentages of cement and aggregate refer to the total mixture~~ of solids.

The limestone aggregate preferably has a $CaCO_3$ content that is greater than or at least equal to 95% by weight compared to the aggregate mass.

Typical mixture according to the invention

As the typical mixture cement plus calcareous aggregate according to the invention, the one in which the calcareous aggregate is type a1 is considered herein.

The CO mixture: cement plus calcareous aggregate that is best adapts to the optimal curve, following the equation [1] wherein A=0.75 is the one below, indicated as “CO mixture”, and which has the composition shown in table VII.

TABLE VII Composition of the CO mixture

Aggregate fraction 0	22.8%
Aggregate fraction 1	35.2%
Aggregate fraction 2	10%
CEM I 52.5R	32%

Figure 6 shows the particle-size distribution of the above-mentioned solid CO mixture and the particle-size distribution curve according to equation [2] for reference.

The CO1 mixture: cement plus calcareous aggregate that is best adapts to the optimal curve, following the equation [1] wherein A=0.822 is the one below, indicated as “CO1 mixture”, and which has the composition shown in table VIII.

TABLE VIII Composition of the CO1 mixture

Aggregate fraction A	30.0%
Aggregate fraction B	15.4%
Aggregate fraction C	4.68%
Aggregate fraction D	10.25%
Aggregate fraction E	10.67%
CEM I 52.5R	29.0%

Figure 7 shows the particle-size distribution of the above-mentioned solid CO1 mixture, the particle-size distribution curve according to equation [1] wherein A=0.822 and the Fuller and Bolomey curves for reference.

In particular, D_{max} for the aggregate fractions is 9.5 mm.

Preparation of mixtures according to the prior art for comparison with the mixtures according to the present invention

Comparison mixture with CEM I 52.5R and limestone in a single size (aggregate a2) C1 mixture

For comparison purposes with the optimised mixture, a mixture was produced that was made up of CEM I 52.5R and limestone in a single size which had a particle-size distribution as shown in figure 8 for the solid C1 mixture, by comparison with the reference curve following the Eq. [1] wherein A=0.75.

The composition of the mixture was as follows:

TABLE IX Composition of the solid C1 mixture

Cement 52.5 R type I	32%
Calcareous aggregate (limestone) in a single size	68%

If one examines figure 8, the considerable variance from the reference curve can be seen in the upper region of the typical particle-size curve of the CEM 52.5R, whose cumulative curve is shown, in relation to its content in the mixture.

Mixture for comparison with CEM 52.5R and silica-calcareous tondo di fiume (aggregate b) C2 mixture.

A mixture of silica-calcareous aggregate and CEM I 52.5 R cement was prepared with the composition shown in table X:

TABLE X. Composition of the C2 mixture (CEM 52.5R and silica-calcareous aggregate).

Sataf 113 aggregate	10.86%
Sataf 103 aggregate	16.85%
Sataf 117R aggregate	37.29%
CEM I 52.5R	33%

Figure 9 demonstrates that the mixture made up of CEM I 52.5R and silica calcareous aggregate has a significant variance from the reference curve, following the equation [1] wherein A=0.75, and tends to resemble the Bolomey by A_B= 14.

Comparison mixture with quartz aggregate (C) (Ductal ®) C3 mixture

In order to compare the performances of the calcareous cementitious mixture and a quartz-based cementitious mixture, the basic mixture (without any fibre reinforcement) known commercially as DUCTAL®, whose solid materials composition is shown in table XI, was examined.

Table XI. Composition of the Ductal® solid mixture

(*) Cement with a high content of silica (C_3S>75%)

Cement 52.5R HTS (*)	32.74%
Vitreous Silica SEPR (Silica Fume)	10.66%
Quartz flour	9.81%
Quartz sand (D max = 0.5 mm)	46.79%

Typical mixture of the invention with cement CEM type III/A, 52.2 R: C4 mixture.

A solid mixture was prepared for a fibre-reinforced concrete mix.

Table XII. Composition of the solid C4 mixture

Cement 52.5 R type III/A*	45%
Aggregate fraction 0	18%
Aggregate fraction 1	28%
Aggregate fraction 2	9%

* the cement used in this solid mixture contains anhydrite, as an activator, as an amount of 3% by weight on the cement.

Preparation of the mixes for the comparison tests.

Various mixes were prepared with the solid mixtures described in the previous paragraphs.

TABLE XIII Composition of the mixes

Mix	**Solid Mixture**	**Water/binder ratio**	**Hyper-fluidifying admixture**
ICO-A	CO	0.26	Acrylic-based admixture 0.6%**
ICO1-A	CO1	0.276	Acrylic-based admixture 0.65%**
ICO-N	CO	0.30	Naphthalenesulphonate-based admixture 2.5%**
IC1-A	C1	0.26	Acrylic-based admixture 0.6%**
IC1-N	C1	0.30	Naphthalenesulphonate-based admixture 1.9%**
IC2-A	C2	0.26	Acrylic-based admixture 0.6%**
IC2-N	C2	0.30	Naphthalenesulphonate-based admixture 2.5%**
IC3-A	C3	0.21	Acrylic-based admixture 1.8%**
IC4-A	C4	0.22	Acrylic-based admixture 0.6%

** admixture as a dry substance in % on the binder

A = acrylic-based admixture (Superflux 2003)

N = naphthalenesulfonate-based admixture (Superflux NF)

Packing procedure for the mixes.

The mixes were prepared used a highly effective "HOBART" mixer. During the first mixing stage, the anchor was turned at the minimum number of rotations 140 ± 5 rpm for 60 seconds, slowly adding water and the admixture; the mixing was continued until a pasty consistency (≅3') was obtained. After this stage, the mixing was faster (285±10 rpm) for another 30". The mixture was then rested for 90" and then the mixture was mixed again at a higher speed for 120". Metal filters were added for the mix with the solid C4 mixture, after the first mixing cycle.

Characterisation of the product according to the invention, compared with products according to the prior art.

Rheological performance

The following table XIV contains the flow% values [Uni 7044] found on the mixes indicated in table XIII.

TABLE XIV Rheological properties of the examined mixes.

Identification no.	Flow %	Notes
ICO-A	170	Self-compacting
ICO-N	182	Self-compacting
IC1-A	130	Thixotropic
IC1-N	190	Self-compacting
IC2-A	130	Thixotropic
IC2-N	>200	Self-compacting
IC3-A	>200	Thixotropic
IC4 A	>200	Self-compacting

A = acrylic-based admixture

N = naphthalenesulfonate-based admixture

ICO = invention

For the mixes ICO-A and ICO1-A, also believed to be the most promising with regards to the development of mechanical strength, rheological characterisation were extended to the purpose of checking the requisites of self-compacting concrete. The results obtained can be seen in table XV and table XVI respectively.

TABLE XV Rheological characterisation of the mix ICO-A

Test	Result	Notes
Slump-flow	760 mm	Positive result
L-box	Complete filling (100%)	Positive result
U-box	At the end of the test, the difference in level between the two chambers was zero	Positive result
Funnel	≦30”	Accentuated cohesion/viscosity properties

TABLE XVI Rheological characterisation of the mix ICO1-A

TEST	TEST RESULT	Reference values (UNI Draft)
FLOW	T_{500}= 12” D_{max}= 750mm	≤12” >600mm
L-box	$h_2/h_1=1$	$h_2/h_1>0.80$
U-box	$\Delta h=0mm$	$\Delta h\leq 30mm$
Flow time	20”	4-12”

As there are no Italian or European regulations, the tests shown above were carried out according to the descriptions given in “M. Ouchi, History of Development and Applications of SCC in Japan – Proceedings of the first international workshop on self-compacting concrete – University of Technology, Kochi, Japan, 1998.

Seasoning of the test pieces.

All the test pieces, packed in metal moulds 40x40x160 mm in size, were dislodged from the moulds 24 hours after casting and were placed for seasoning in water at 20 ± 2°C until the pre-set deadline. It proved necessary to extend the keeping of the test pieces in the mould for 48 hours instead of 24 hours solely for the test pieces identified as IC3 (Ductal®) as that they did not show clear signs of hardening (the deadline of 48 hours is the one indicated in the already quoted patent WO 99/28267.

Shrinkage during the plastic phase

Shrinkage tests during the plastic phase were carried out on some of the mixes indicated in table XIII (ICO-A, ICO1-A and IC3-A).

The behaviour of the ICO-A mix, and more over for the ICO1-A mix, were highlighted, characterised by a much more limited shrinkage during the plastic phase than that found in the quartz aggregate and vitreous silica based mix IC3-A (see figure 10).

Strength performances

Table XVII. Compressive strength values [MPa] found according to EN. 196.1 for the mixes prepared with an acrylic admixture

Mix	24 hours	2 days	7 days	28 days
ICO-A	79.45	99.18	122.4	138.37
IC1-A	49.7	61.92	76.71	83.17
IC2-A	51.7	84.76	98.7	108.0
IC3-A	91.5	98.4	125	136.3

Note. The deadline dates of the mix IC3-A should actually be moved by two days (e.g. the 1 day value was actually taken 1 day after removal from the mould and therefore 3 days after mixing)

On examining the data contained in tables XIV and XVII the following conclusions can be made:

1) When using the acrylic admixture, with an equal water/cement ratio, only the ICO-A mix allows self-compacting concretes to be obtained.
2) The development of mechanical strength over time for the concrete from the ICO-A mix of the invention is certainly better than that of the comparison mixes IC1-A, IC2-A and IC3-A. Note in particular the marked differences in mechanical strength for the mixes made from the dry matrixes C0 and C1 for which the chemical compositions and the shape or morphology of the aggregates are the same.
3) It is possible to obtain concrete, without a pozzolanic addition, that has a mechanical strength close to 140 MPa after 28 days.

Table XVIII Compressive strength values [MPa] found according to EN 196.1 for the mixes prepared with a naphthalenesulfonate admixture

Mix	24 hours	2 days	7 days	28 days
ICO-N	54.6	80.71	98.06	112.92
IC1-N	44.66	60.7	76.36	88.74
IC2-N	32.4	72.52	89.52	101.84

On examining the data contained in table XVI, the following conclusions can be made:

1) The development of mechanical strength over time for the concrete from the ICO-N mix of the invention is certainly better than that of the comparison mixes IC1-N and IC2-N. Note in particular the marked differences in mechanical strength for the mixes made from the dry matrixes C0 and C1 for which the chemical compositions and the shape or morphology of the aggregates are the same.

2) It is possible to obtain a concrete, without a pozzolanic addition, that has a mechanical strength exceeding 100 MPa after 28 days.

It is a known fact that the reinforcement action carried out by a steel fibres system on a cementitious matrix depends, in equal conditions, on the bonding between the fibres and the matrix itself.

The adhesion of the fibres to the cementitious matrix is usually entrusted to the mechanical anchoring that, as is known, depends on the length (or more precisely on the length/diameter ratio) of the fibres and their shape. For this reason, the steel fibres usually have a suitable shape (hook, wavy, tapered at the ends etc) to ensure adequate mechanical bonding. The use of shaped fibres, or fibres with high aspect ratios can however lead to a higher penalisation of the rheological performance of the mixes.

For this reason in the specific case, non-shaped fibres were preferred, which were 16 mm long and with a diameter of 0.13 mm, so as not to compromise the rheological performance of the mixture.

Table XIX. Compressive strength values in MPa found according to EN 196.1 for the mix IC4-A containing fibres.

Mix	24 hours	2 days	7 days	28 days
IC4 A (fibres present as 1% in volume)	99.1	102.6	141.3	152.0

Table XX. Flexural strength values in MPa found according to the EN 196.1 for the mix IC4-A containing fibres.

Mix	24 hours	2 days	7 days	28 days
IC4-A (fibres present as 1% in volume)	15.7	20.0	23.7	27.4

As can be seen, the addition of steel fibres determines a substantial increase in mechanical strength, as the mechanical strength values are already near to 100 MPa 24 hours after the mix is made up.

Table XXI. Mechanical strength values in MPa found according to the corresponding EN directive, for the mix ICO1-A.

TIME [d]	Compressive strength [MPa]	Flexural Strength [MPa]	Modulus of Elasticity* (dynamic) [MPa]
1	85	10,8	43 491
2	92	15,2	44 900
7	103	18,9	46 000
28	118,5	20,6	48 100

* Modulus of Elasticity according to UNI 9771.

1. A solid mixture for the preparation of concrete with a mechanical compressive strength after 28 days that is greater than or equal to 110 MPa, comprising cement, calcareous aggregates and at least one recognized concrete admixture, and Pozzolan or fly ash type II additions according to the EN 206 regulation in amount less than 5% by weight of the cement, wherein the particle-size distribution of the mixture is shown on the graph of the cumulative percentage of passing material according to the size of the particles in mm, from a curve that substantially corresponds to the values shown in the following table:

Diameter (mm)	Undersize %
0.002	5 – 12
0.005	10 – 13
0.01	15 – 20
0.1	30 – 40
0.2	40 – 60
0.4	50 – 75
0.7	60 – 85
1	70 – 90
2	85 - 95

.

2. The solid mixture according to claim 1 wherein the cement is a cement that is compliant with the European regulation 197-1.

3. The solid mixture according to claim 1 for the preparation of concrete with a mechanical compressive strength after 28 days that is greater than or equal to 110 MPa, characterised by the fact that the Pozzolan or fly ash type II additions according to the EN 206 regulation are less than 2% by weight of the cement.

4. The solid mixture according to claim 1 for the preparation of concrete that over time has the following development of mechanical compressive strength:

after one day: ≥ 50 MPa; after 2 days: ≥ 80 MPa; after 28 days: ≥ 110 MPa.

5. The solid mixture according to claim 3 for the preparation of concrete that over time has the following development of mechanical compressive ~~strengths~~ strength:

after one day: ≥ 50 MPa; after 2 days: ≥ 80 MPa; after 28 days: ≥ 110 MPa.

6. The solid mixture according to the claim 1 wherein the cement is CEM I 52.5 R.

7. The solid mixture according to claim 1 wherein the cement is CEM III A 52.5 R, with a slag content of 40% by weight of the clinker.

8. The solid mixture according to claim 1 wherein the cement is present from 25% to 50% by weight of the total solid mixture.

9. The solid mixture according to the claim 8 wherein the cement is present from 30% to 35% by weight of the total solid mixture.

10. The solid mixture according to claim 1 wherein the calcareous aggregates are crushed calcareous aggregates with a $CaCO_3$ content that is greater than or equal to 95% by weight of the total weight of the aggregate.

11. The solid mixture according to claim 1 wherein the calcareous aggregates have a D_{Max} (maximum Diameter) from 2 mm to 12 mm.

12. The solid mixture according to claim 11 wherein the calcareous aggregates have a D_{Max} (maximum Diameter) from 4 to 8 mm.

13. The solid mixture according to claim 11 wherein the calcareous aggregates have a D_{Max} (maximum Diameter) from 8 to 12 mm.

14. The solid mixture according to claim 11 wherein the calcareous aggregates have a D_{Max} (maximum Diameter) of 9.5 mm.

15. The solid mixture according to claim 1 wherein the admixtures are either acrylic or naphthalenesulfonate admixtures.

16. The solid mixture according to claim 15 wherein the acrylic admixtures are present from 0.4% to 1.2% by weight of the weight of the cement.

17. The solid mixture according to claim 16 wherein the acrylic admixtures are present from 0.5% to 0.8% by weight of the weight of the cement.

18. The solid mixture according to claim 15 wherein the naphthalenesulfonate admixtures are present from 1.9% to 2.5% by weight of the weight of the cement.

19. The solid mixture according to claim 1 further comprising metal fibres.

20. A cementitious mix for the preparation of concrete with a mechanical compressive strength after 28 days that is greater than or equal to 110 MPa comprising a solid mixture according to claim 1 characterised by the fact that any Pozzolan or fly ash type II additions according to the EN 206 regulation are less than 5% by weight of the cement and that have a water/cement ratio from 0.2 to 0.3.

21. The cementitious mix according to claim 20 characterised by the fact that the water/cement ratio is from 0.24 to 0.26.

22. A concrete with mechanical compressive strength after 28 days that is greater than or equal to 110 MPa comprising a solid mixture according to claim 1, characterized by the fact that any Pozzolan or fly ash type II additions according to the EN 206 regulation are less than 5% by weight of the cement.

23. The concrete according to claim 22 with a mechanical compressive strength after 28 days that is greater than or equal to 110 MPa comprising a solid mixture according to claim 1, characterized by the fact that any Pozzolan

or fly ash type II additions according to the EN 206 regulation are less than 2% by weight of the cement.

24. A solid mixture for the preparation of concrete with a mechanical compressive strength at 28 days that is ≤ 110 MPa, based on cement and calcareous aggregate, containing Pozzolan or fly ash type II additions according to the EN 206 regulation in quantities less than 5% by weight of the cement, characterized by the fact that the particle-size distribution of the mixture is shown on the graph of the cumulative percentage of passing material according to the size of the particles in mm, from a curve that substantially corresponds to the values shown in the following table:

Diameter (mm)	Undersize %
0.002	5 – 12
0.005	10 – 13
0.01	15 – 20
0.1	30 – 40
0.2	40 – 60
0.4	50 – 75
0.7	60 – 85
1	70 – 90
2	85 - 95

25. The solid mixture based on cement and calcareous aggregate according to claim 24 wherein the aggregate of mainly calcareous type is limestone.

Fig.1

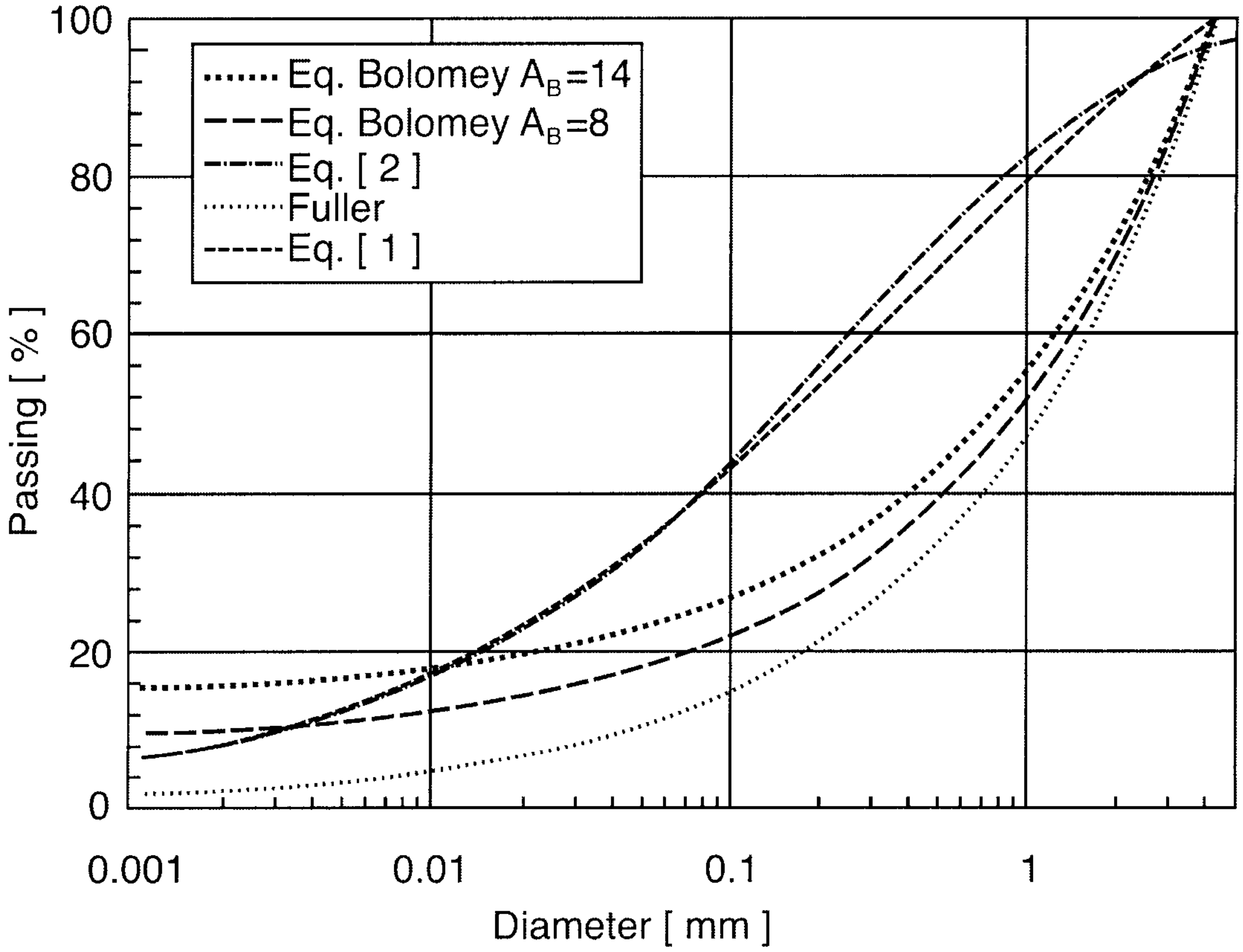

Eq. Bolomey A_B=14
Eq. Bolomey A_B=8
Eq. [2]
Fuller
Eq. [1]
Passing [%]
0
20
40
60
80
100
0.001
0.01
0.1
1
Diameter [mm]

Fig.2

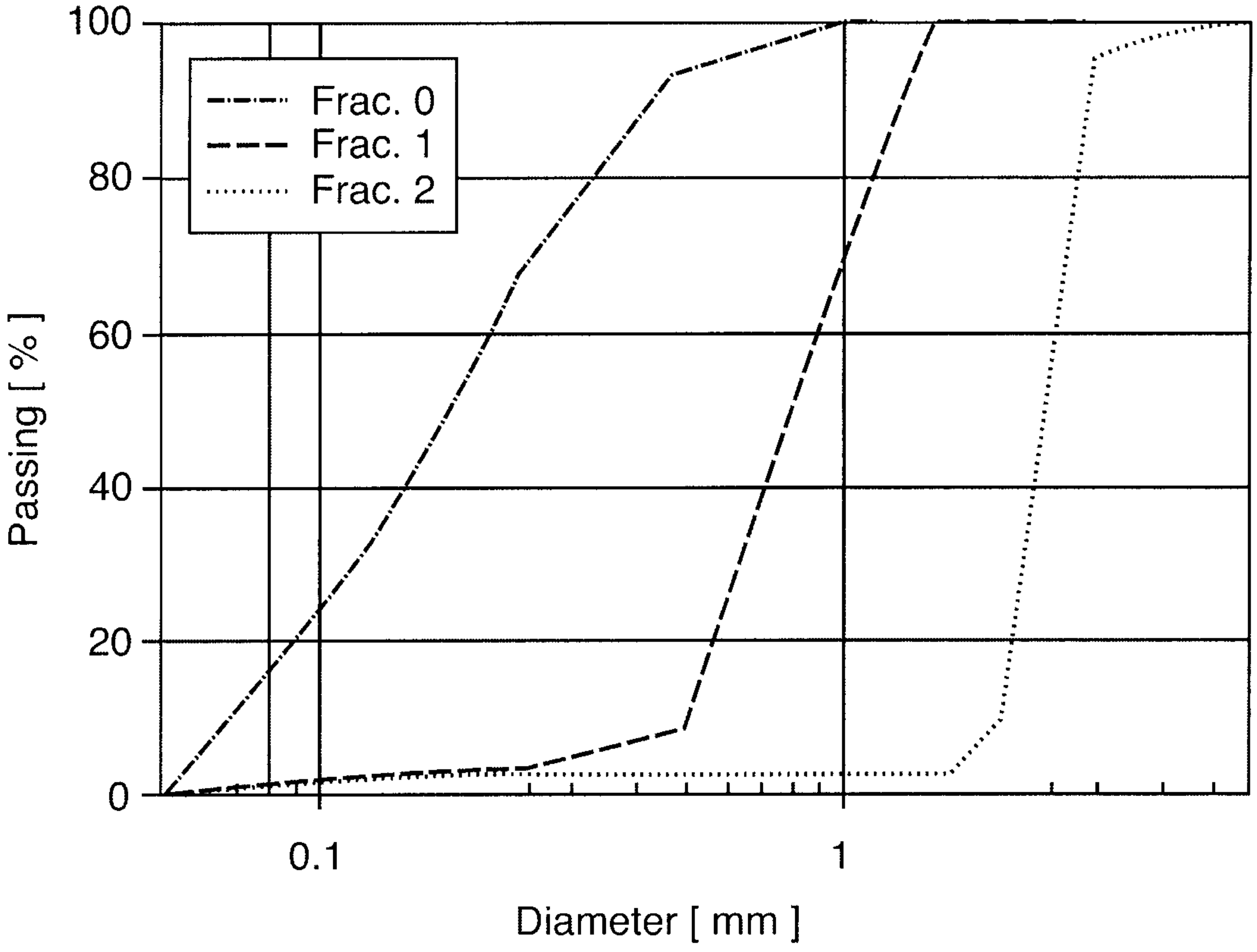


FIGURE 3

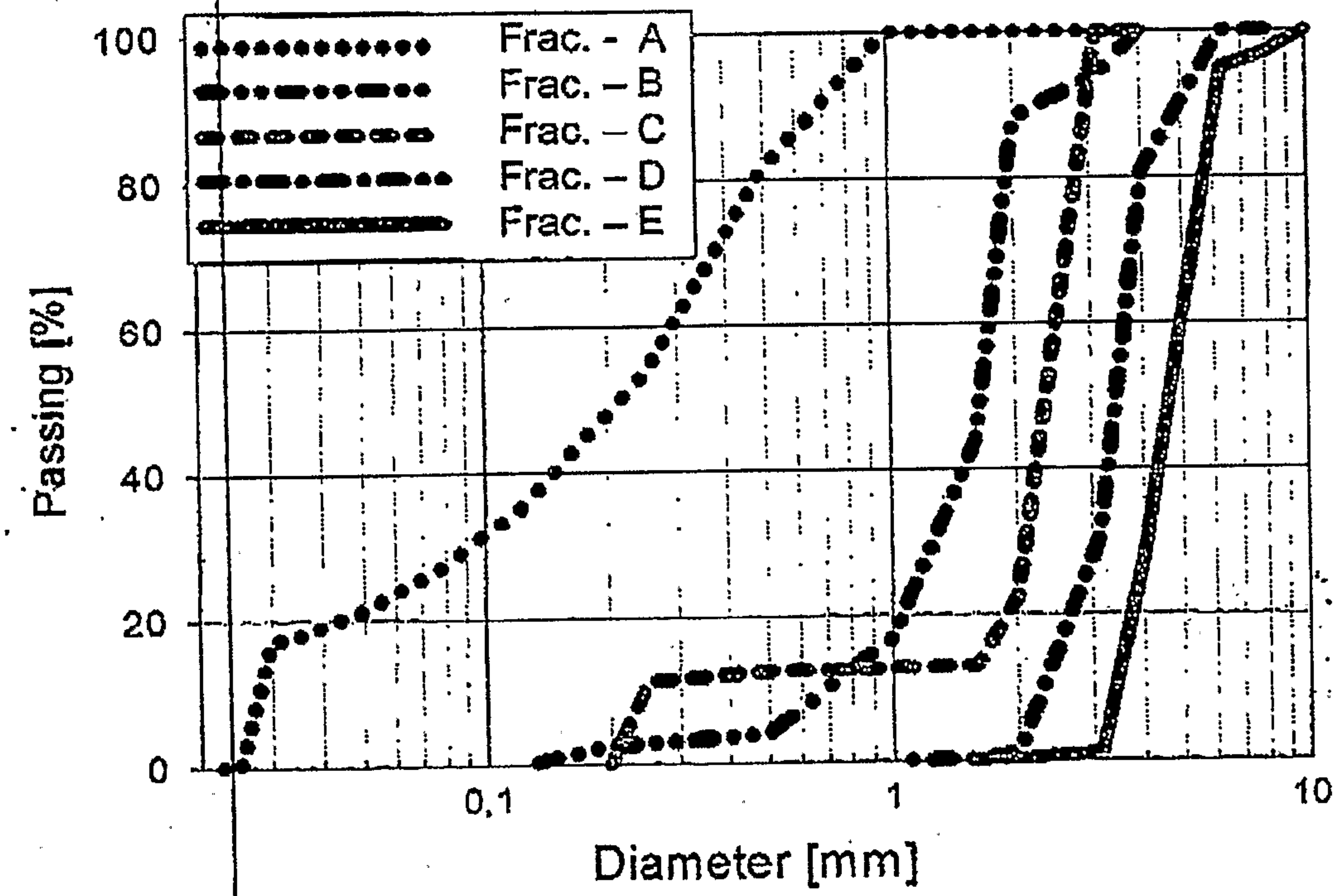

Frac. - A
Frac. – B
Frac. – C
Frac. – D
Frac. – E
100
80
60
40
20
0
Passing [%]
0,1
1
10
Diameter [mm]

FIGURE 4

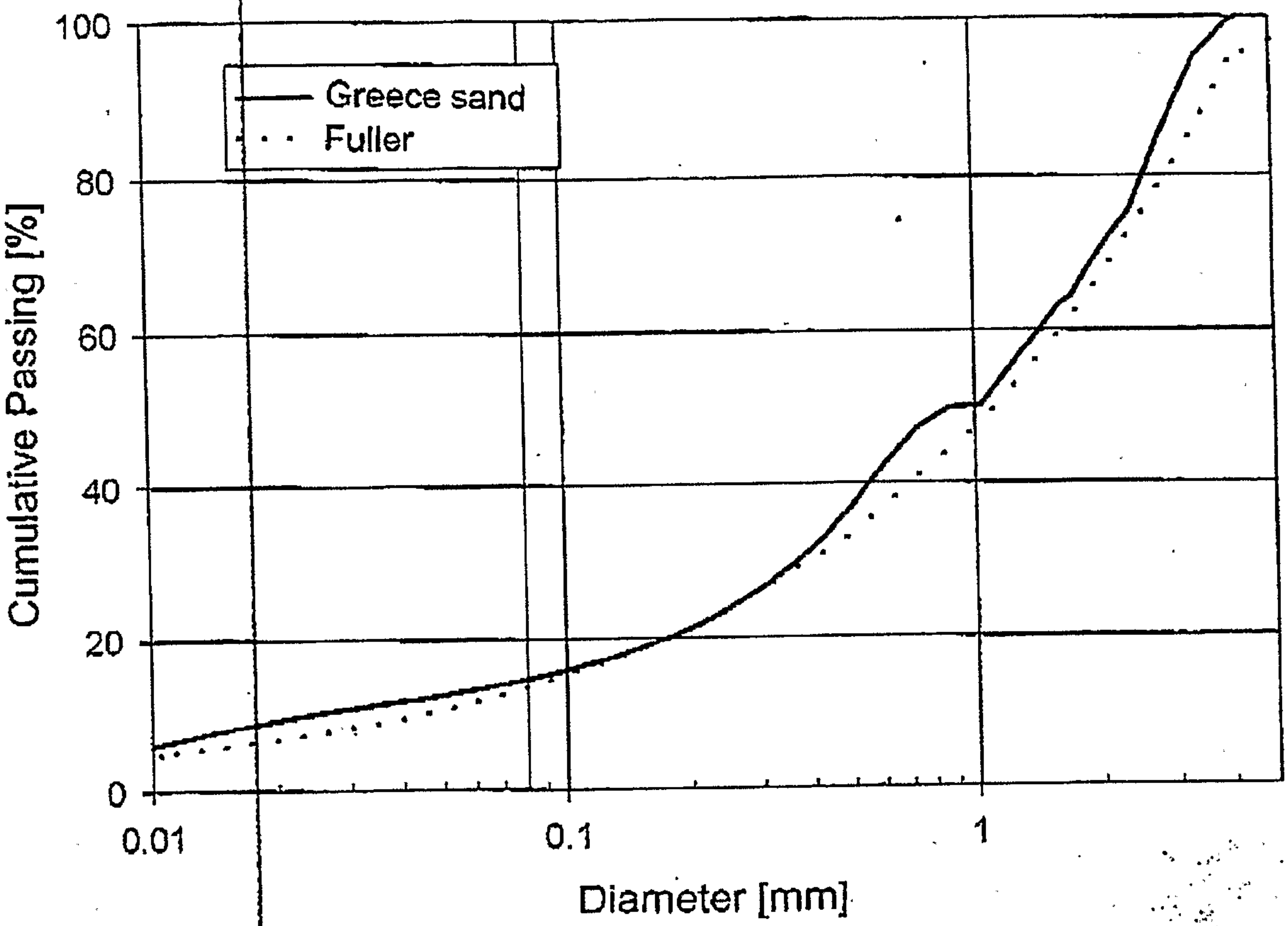

Greece sand
Fuller
Cumulative Passing [%]
100
80
60
40
20
0
0.01
0.1
1
Diameter [mm]

Fig.5

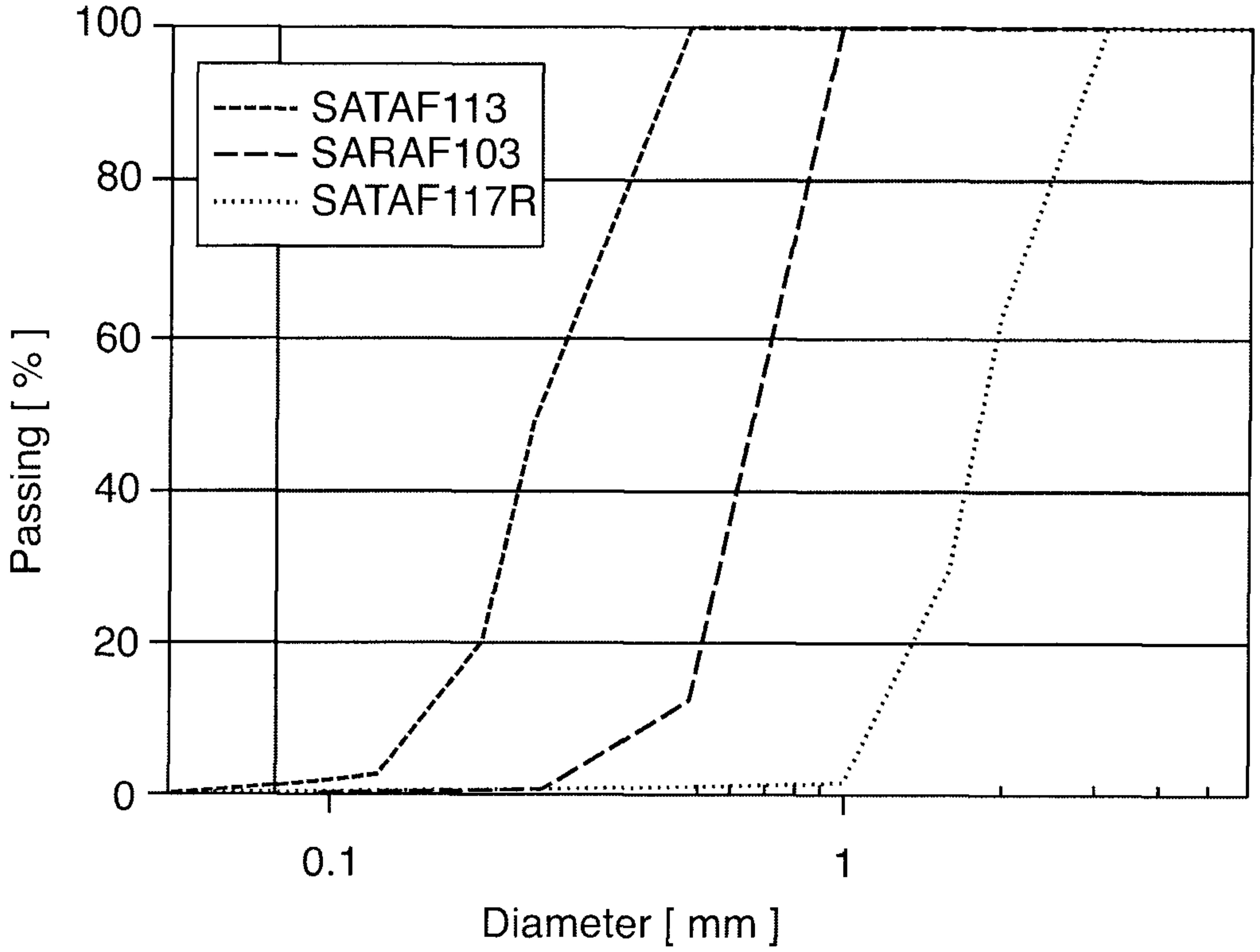

100
80
60
40
20
0
Passing [%]
0.1
1
Diameter [mm]
SATAF113
SARAF103
SATAF117R

FIGURE 6

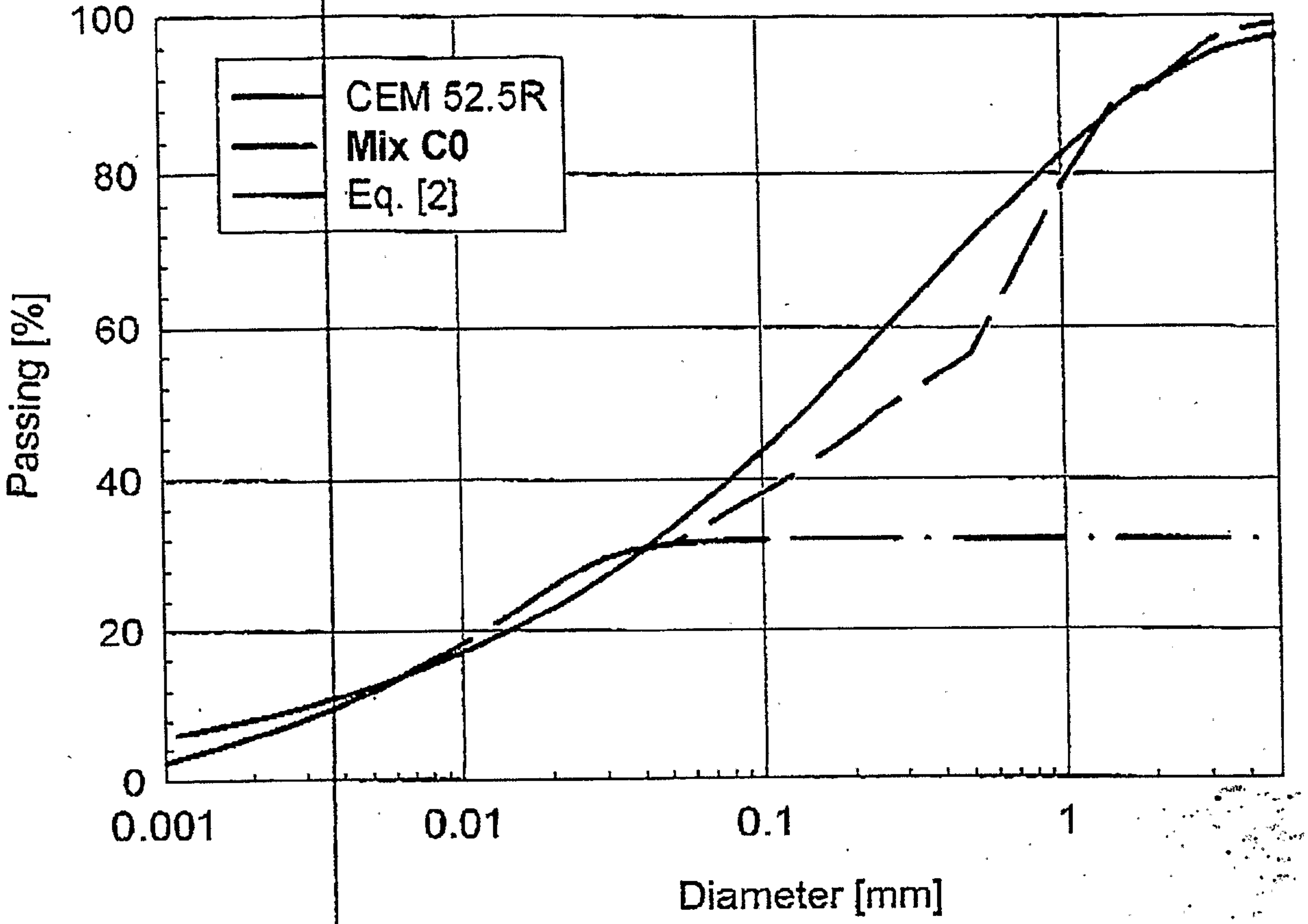

100
80
60
40
20
0
0.001
0.01
0.1
1
Passing [%]
Diameter [mm]
CEM 52.5R
Mix C0
Eq. [2]

FIGURE 7

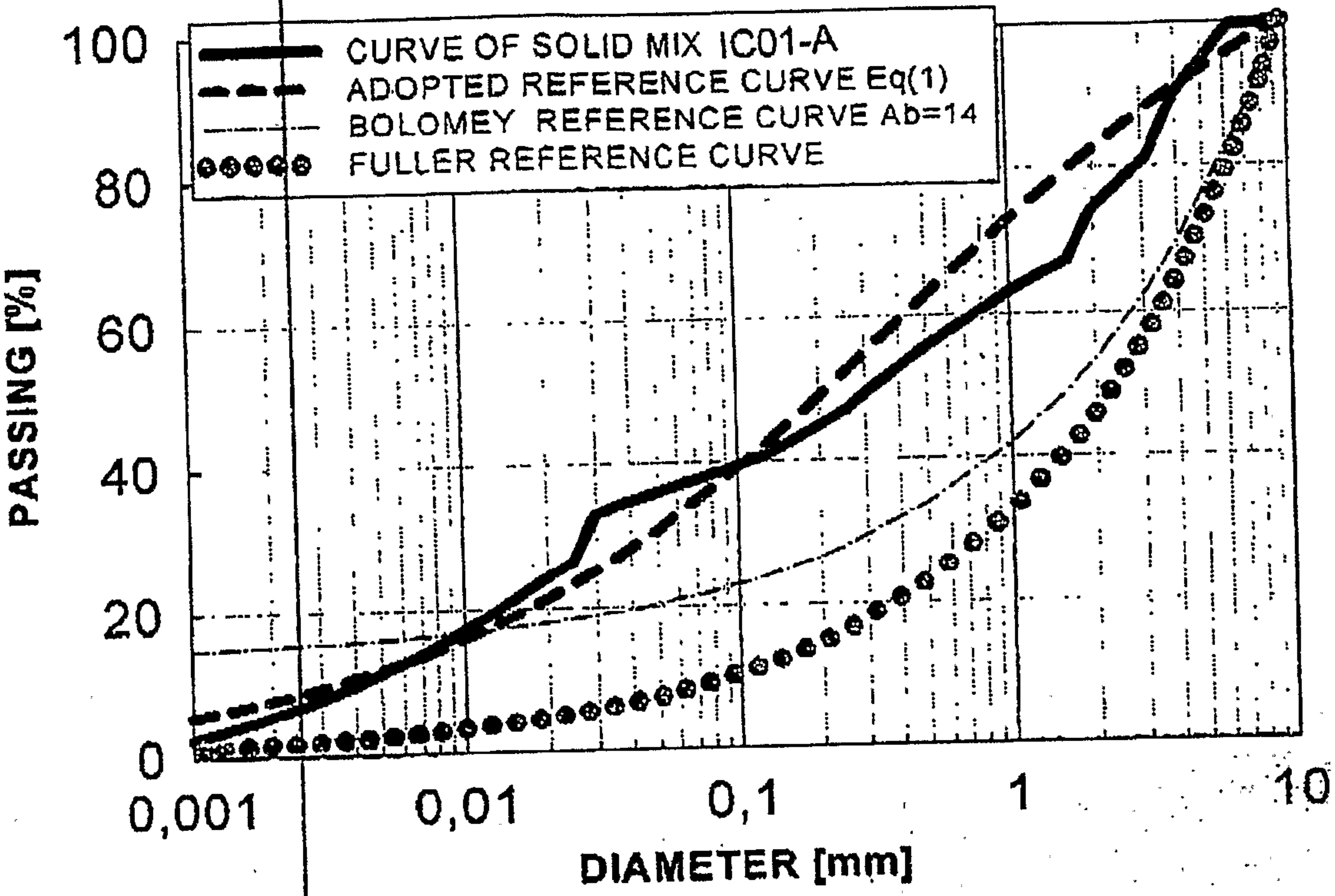

CURVE OF SOLID MIX IC01-A
ADOPTED REFERENCE CURVE Eq(1)
BOLOMEY REFERENCE CURVE Ab=14
FULLER REFERENCE CURVE
100
80
60
40
20
0
PASSING [%]
0,001
0,01
0,1
1
10
DIAMETER [mm]

Fig.8

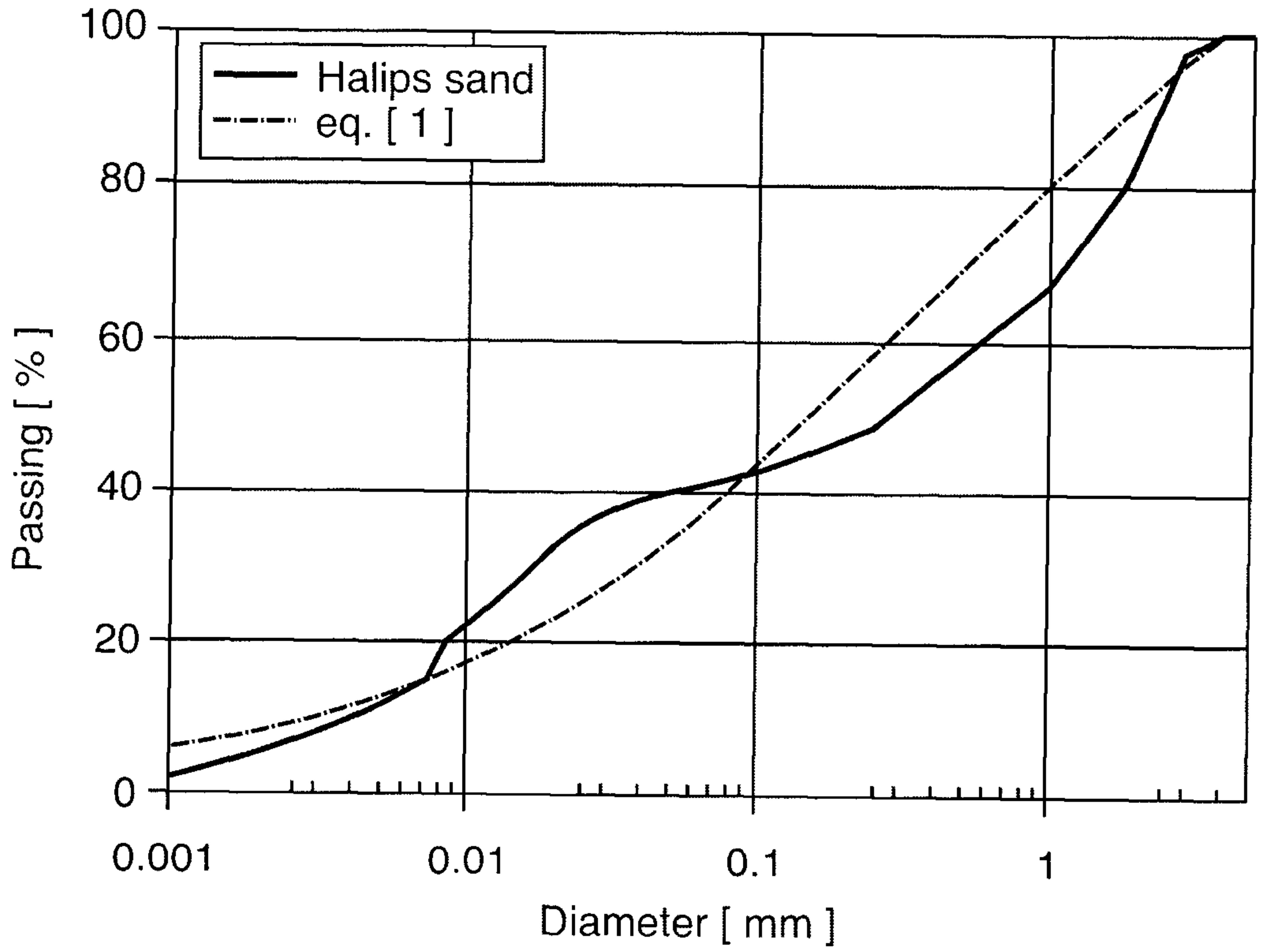

100
80
60
40
20
0
Passing [%]
Halips sand
eq. [1]
0.001
0.01
0.1
1
Diameter [mm]

Fig.9

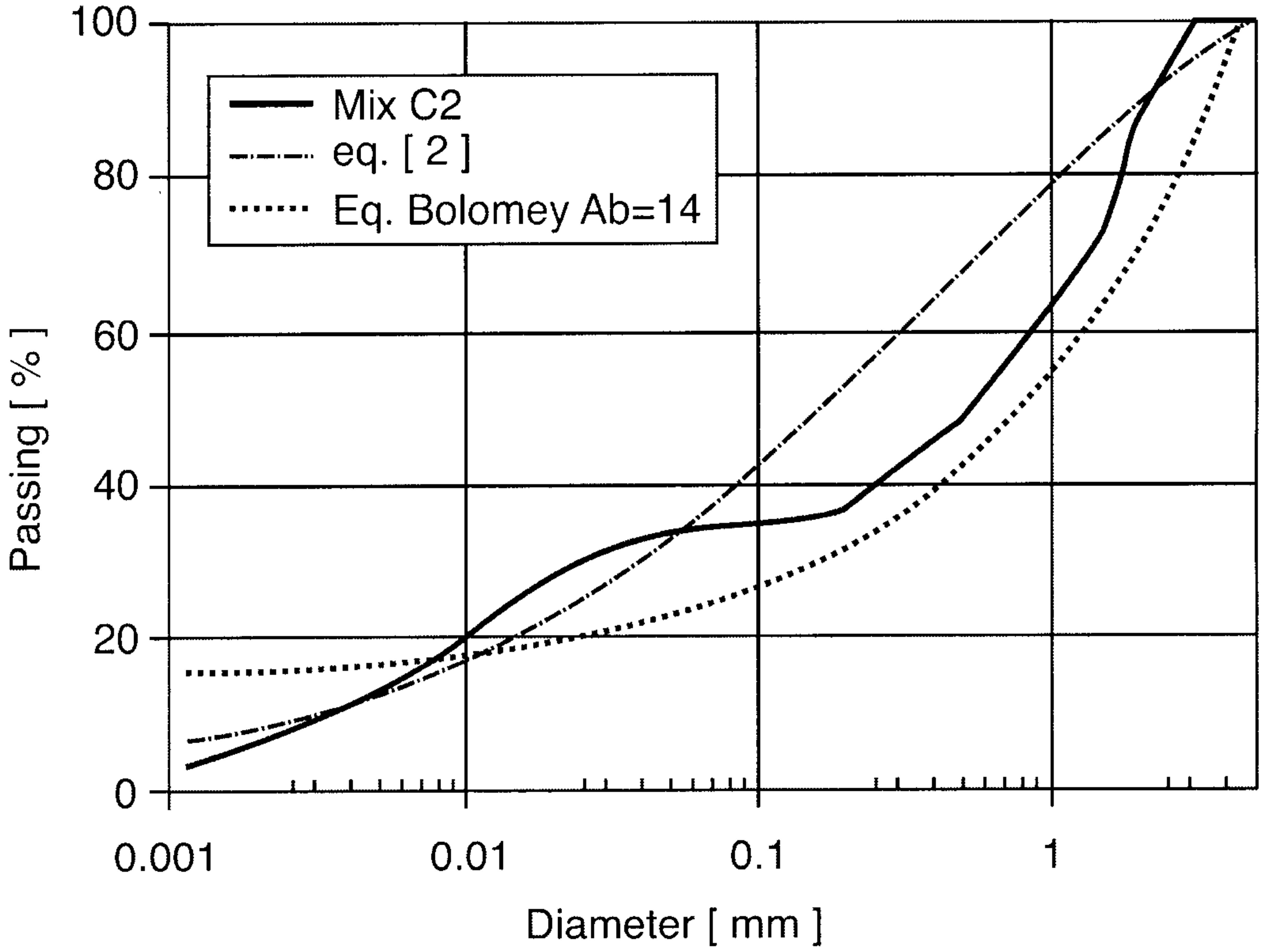
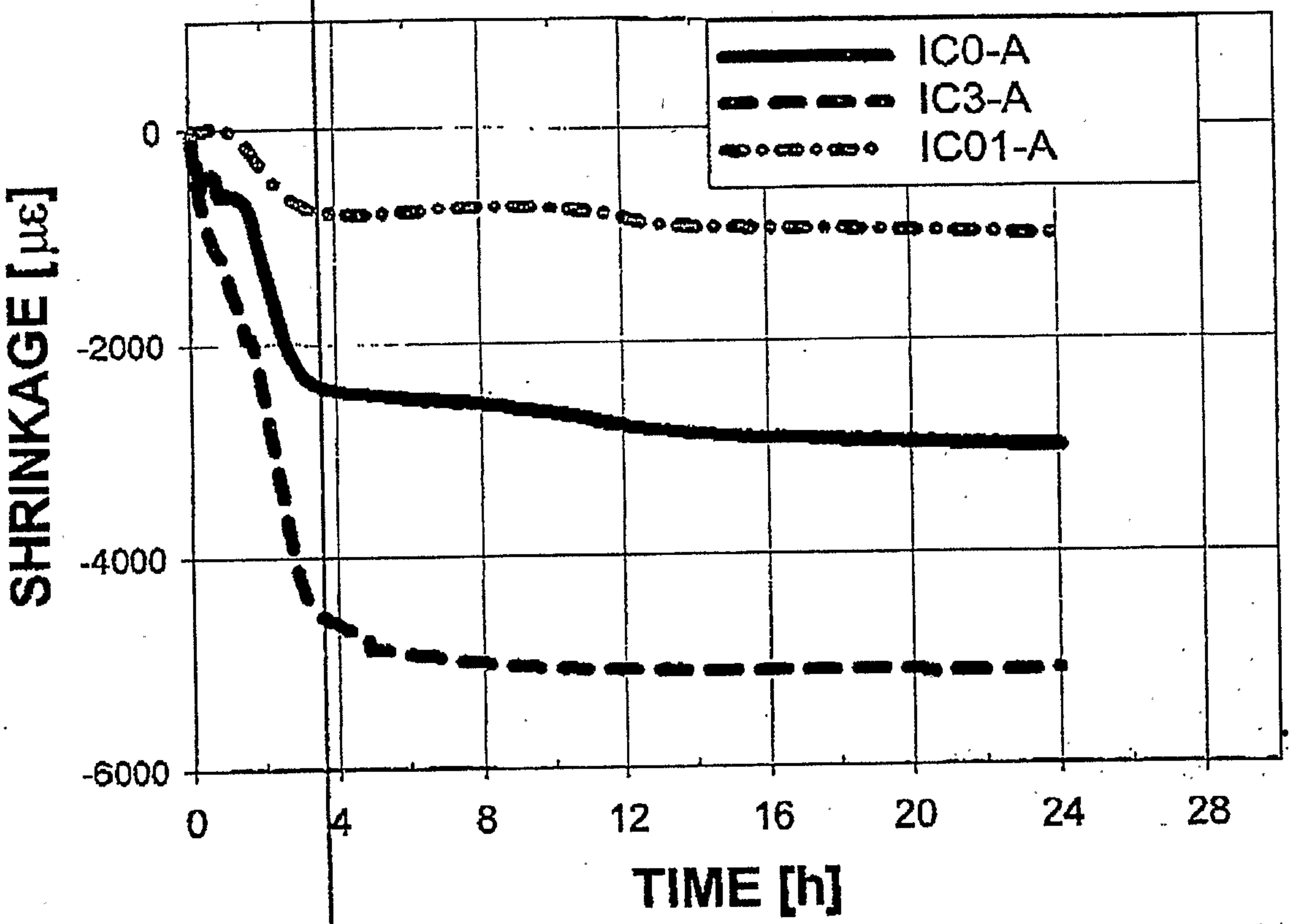

Mix C2
eq. [2]
Eq. Bolomey Ab=14
Passing [%]
0
20
40
60
80
100
0.001
0.01
0.1
1
Diameter [mm]

FIGURE 10


IC0-A
IC3-A
IC01-A
0
-2000
-4000
-6000
SHRINKAGE [με]
0
4
8
12
16
20
24
28
TIME [h]