HOW FLEXIBLE ARE "FLEXIBLE" MORTARS?

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Ceramic tile and stone installation, once a traditional craft, has evolved into a complex, high technology trade requiring a solid technical background, a complete knowledge and a thorough understanding of all environmental conditions, performance requirements, chemical and physical properties of the surfacing materials and substrate if a trouble-free long term service installation is to be achieved.

Compared to the relatively limited variety of tiles which were being produced only decades ago, today's design requirements call for a much broader tile selection which include very large modular sizes, impact, wear and chemical resistant tiles having an extremely low water absorption and the highest frost resistance.

At the same time, the much greater variety of substrates and substrate conditions presently encountered requires special attention: it is more and more common and often necessary that tiles be installed directly over partially cured or lightweight concretes, precast concrete slabs, asphalt, exterior grade plywood, drywall panels, insulation panels, crack suppression and waterproofing membranes, and other non-traditional supports.

For all the above reasons, adhesives manufacturers have maintained for years extensive research and development programs allowing them to produce "FLEXIBLE" adhesives which can provide good adhesion and high elastomeric properties capable to absorb differential movements between tile and substrate layers. Originally, it was found that two types of adhesives could provide a high degree of flexibility. Unfortunately, because of some of their other characteristics, they had serious limitations to their universal usage. These adhesives are:

A) -READY-TO-USE ADHESIVE PASTES: (Also called "ORGANIC ADHESIVES" OR "MASTICS".)

B) -CHEMICALLY REACTIVE ADHESIVES

A) -READY-TO-USE ADHESIVE PASTES

Adhesive pastes (organic adhesives) are essentially a mixture of synthetic polymers and mineral fillers which contain no Portland cement. Although very "FLEXIBLE" these adhesives are generally extremely water sensitive and therefore cannot be used for exterior installation or in conditions of constant water immersion such as in pools, fountains, and jacuzzis.

Furthermore, since most of these adhesives are water-based, their drying or curing process relies solely on the evaporation of the water, making them not too suitable for tile on tile installations or for setting tile on impervious and low absorption substrates. Their downtime requirements could be very long.

B) - CHEMICALLY REACTIVE ADHESIVES

These are generally very flexible polyurethane adhesives. Some are two-component materials requiring personal protection and good ventilation during installation and curing. Besides these disadvantages, they are also famous for their high cost.

Further research led manufacturers to the concept of modifying standard Portland cement dry-set mortars with latex and other polymers to make them "Flexible" while maintaining their costs at acceptable levels. Two different approaches have been taken by various producers to develop modified Portland cement mortars designated as "Flexible":

A) -Portland cement dry-set mortars modified with "spray-dried" water dispersible polymers and supplied in a single component powder form to be mixed solely with water.

B) -Portland cement dry-set mortars modified with a "Liquid-added" latex or polymer. These mortars are supplied in two-components: a cementitious powder and a liquid "polymer milk" used in the mix as a substitute to water.

In order to understand and evaluate properly the merits of each system, comparative "flexibility" tests and "bond strength" tests were conducted using standard non-modified dry-set mortars, "dry" polymer-modified dry-sets, "liquid-added" polymer-modified dry-set mortars, ready-to-use adhesives (organic mastics) and chemically reactive polyurethane adhesives from different manufacturers around the world. Since the sample materials came from different countries, the test method had to be chosen based on the most representative standard method available. This was not going to be an easy choice. Consequently it was decided as possibly being extremely interesting to carry out 4 parallel tests following 3 recognized standard methods:

- The UEAtc directives for Ceramic Tile Adhesive.
- ANSI A118.4 American National Standard Specifications for latex Portland cement mortar.
- DIN 53265 Standard regarding the elastomeric properties of ceramic floor and wall tile adhesives.
- and one following the proposed method developed by the French C.S.T.B.

Furthermore, concerning the more representative cementitious mortar systems on the market, tests were carried out on experimental formulations to determine the influence of the polymer contents on the final performance of the various modified systems.

THE TESTS

All tests were conducted using a plotter equipped computer controlled INSTRON Mod.6027 dynamometer. An EXTENSOMETER with a precision of 0.1 MICRON was used to measure the elastomeric deformation during the DIN, UEAtc and ANSI standard tests.

The test procedures were as follows:

DIN 53265

A series of test specimens consisting of 2 pieces of 50 X 50 mm ceramic tiles were mounted offset and back to back with a 1,5 mm thick layer of adhesive or cementitious mortar as shown in figure 1. 1,5 mm spacers were used to regulate the amount of adhesive in each specimen. The sample assemblies were divided into 2 sets and cured separately as follows:

1) 28 days at 23°C and 50% R.H.
2) 28 days at 23°C and 50% R.H. plus 7 days at 70°C plus 7 days at 23°C and 50% R.H.

After completion of the curing cycle, the specimens were sheared apart either by load or by tension using the apparatus outlined in figure 1. Load and deformation values at point of rupture were recorded.

However, it should be noted that with this test method, it was quite hard to obtain reproducible test specimens because such small ceramic tiles are difficult to handle and a 1,5 mm thickness of adhesive or mortar is a quantity which is at the lower limit of what is normally used. Keeping the two tiles parallel with each other was not easily achieved either and required special attention. Therefore, for good consistent reproducibility, a large number of specimen assemblies had to be prepared to compensate for the broad range of results obtained.

ANSI A118.4

This is essentially a load test on 50 x 50 x 50 mm mortar cubes cured for 28 days at 23°C and 50% R.H. according to ASTM C109 test method. (See figure 2.)

This first cube was loaded to the point of rupture and the load value recorded. The next 2 cubes were then loaded **to only half the breaking load** determined on the first specimen and released. Each specimen was subjected to 2 load/release cycles and reloaded until ruptured. The modulus of elasticity was established from the strain curve plotted on the two last specimens. The use of an extensometer was found to be determining in this case, especially with brittle or slightly flexible mortars. The percentage of error caused by the strain on the apparatus in very high when such materials are tested.

1979 UEAtc Directive

Each test specimen consisted of 2 parallel concrete bars sandwiched between 2 pieces of 108 x 108 x 5 mm ceramic tiles and assembled together with a 1,5 mm thick layer of adhesive or mortar on each side of the sample as shown in fig. 3.

The specimens were then divided into 2 sets and cured separately in similar conditions as already described for the DIN 53265 test as follows:

1)28 days at 23°C and 50% R.H.
2)28 days at 23°C and 50% R.H. plus 7 days at 70°C plus 7 days at 23°C and 50% R.H.

After the curing cycles were completed, each specimen was subjected to load forces applied to the horizontal concrete bars until shearing occurred. Load and deformation values were recorded.

Here again, the preparation of the specimens required special attention particularly to ensure perfect parallelism of both, bars and tiles.

C.S.T.B. Proposed Test

In this case, the test specimens were prepared by spreading a 3 mm thick layer of adhesive or mortar on a 300 x 80 x 5 mm strip of polystyrene having a density of 15 kg per cubic meter. The specimens were divided into 2 sets and cured separately in the following conditions:

1) 28 days at 23°C and 50% R.H.
2) 28 days at 23°C and 50% R.H. plus 14 days at 60°C plus 1 day at 23°C and 50% R.H.

Once completely cured, the specimens were subjected to a flexural test using a simple apparatus as outlined in figure 4. Load and deformation values were recorded at point of rupture.

The advantage of this test proposal lies in the simplicity of the specimen preparation and in the elimination of unnecessary handling of test samples. In addition, it is the only test method not requiring the use of an extensometer. Because of light pressure loads and heavy deflection involved in this test, the margin of error due to high strain loads on the apparatus becomes negligible.

The only critical aspect of this test lies in the choice of the polystyrene strip. Differences in thickness and density of the material can have an important impact on the final results.

RESULTS ANALYSIS

When tested in accordance with the proposed C.S.T.B. method, (Bar graph 1) there were some noticeable flexural differences between various specimens of the non-modified normal dry-set mortars. This may be caused by the different degrees of compactness and the relative cohesive strength of the individual mortar specimens.

The single-component spray-dried dispersible polymer-modified mortar graph shows that 80 - 85% of these mortars averaged out to very similar flexural values as those obtained with non-modified systems. In this case, the only advantage of polymer modification resided in the increased bond strength. Although nearly all of these products are described with the magic word "FLEXIBLE", only 15 - 20% of the test specimens showed greater "Flexibility" than non-modified mortars.

Ready-to-use adhesives (organic adhesives), chemically reactive adhesives and modified dry-set mortars with liquid added polymers form the third group of products represented on this graph. It is obvious that these products had a distinct flexural advantage over the other two groups and that consequently, they should be the only ones designated as truly "FLEXIBLE".

It is interesting to note that the "flexibility" of the mortar systems increases proportionately with the amount of latex or "polymer milk" added into the system, and that the addition of a cut-down 1:4, (latex:water) solution, presents no "flexibility" advantage over non-modified dry-set mortars. Very similar values were recorded.

Bar graph 2 shows results obtained after testing the same groups of materials according to the **DIN 53265** standard method. This graph further emphasizes that ready-to-use adhesives, chemically reactive adhesives and modified dry-set mortars with "liquid-added" polymers are truly "FLEXIBLE", while the single-component dispersible dry polymer modified systems and non-modified dry-sets show very little differences between each other.

Tests results using the UEAtc standard method as plotted on bar graph 3 dramatically confirm the observations previously reported.

The relative flexibility of the various mortar systems based on results from ANSI A118.4 Elastic Modulus tests (ASTM C109) is reported on graph 4. Even though these results are based on test loads applied to cubic specimens the differences between the various groups of adhesives are again clearly confirmed.

Finally, the average results from the four testing procedures are summarized in bar graph 5. Regardless of the test method, the distinct superiority of the "liquid-added" modified systems in terms of flexibility has been proven although the C.S.T.B. proposal seems best suited for the purpose of analyzing and illustrating the "FLEXIBLE" characteristics of any mortar system.

At this point, the discussion is still open as to which is the simplest and best reproducible test method and as to which standard requires the least expensive apparatus. Nevertheless, there is certainly no doubt that by whichever standard the only products presently on the market which can be considered truly "FLEXIBLE" are as follows:

- Ready-to-use adhesives, also referred to as "organic adhesives" or "mastics", - (usually styrene-acrylic based)
- Chemically reactive adhesives (more specifically polyurethane adhesives)
- Dry-set mortars modified with liquid-added latex or "polymer milk"

As a complement to this study, a comparative analysis based on the C.S.T.B. proposed method was carried out on 3 different laboratory prepared formulations, modifying a standard commercial dry-set mortar (MAPEI's KERABOND used as the basic reference) with:

1. A "soft" spray-dried water dispersible polymer
2. A "hard" or "brittle" spray-dried water dispersible polymer
3. A commercially available "liquid polymer milk" (MAPEI's ISOLASTIC)

The polymer content was gradually increased to determine the effects on the "Flexibility" of the dry-set mortar.

The results of these tests were plotted on bar graph 6, and the following conclusions may be drawn:

1. There are no substantial differences between the use of "soft" or "hard" polymers in the systems
2. Considerable amounts of polymers must be used in order to achieve good "Flexibility"
3. Decidedly, in all cases, the use of **liquid polymer milks** generates much superior values in terms of flexibility for the same amount of polymer in the mix.

It is important to remember that in addition to being "FLEXIBLE", any given modified dry-set mortar **must exceed the minimum bond strength requirements** of the governing standards of the country in which they are being used. (ANSI in the U.S.A., CGSB in Canada, UEAtc in Europe, etc.) Nevertheless, it is generally recognized that spray-dried dispersible polymers have a very weak resistance to water. Therefore the use of large amounts of these polymers to modify cementitious dry-set mortars will increase the risk of poor adhesion in the presence of water.

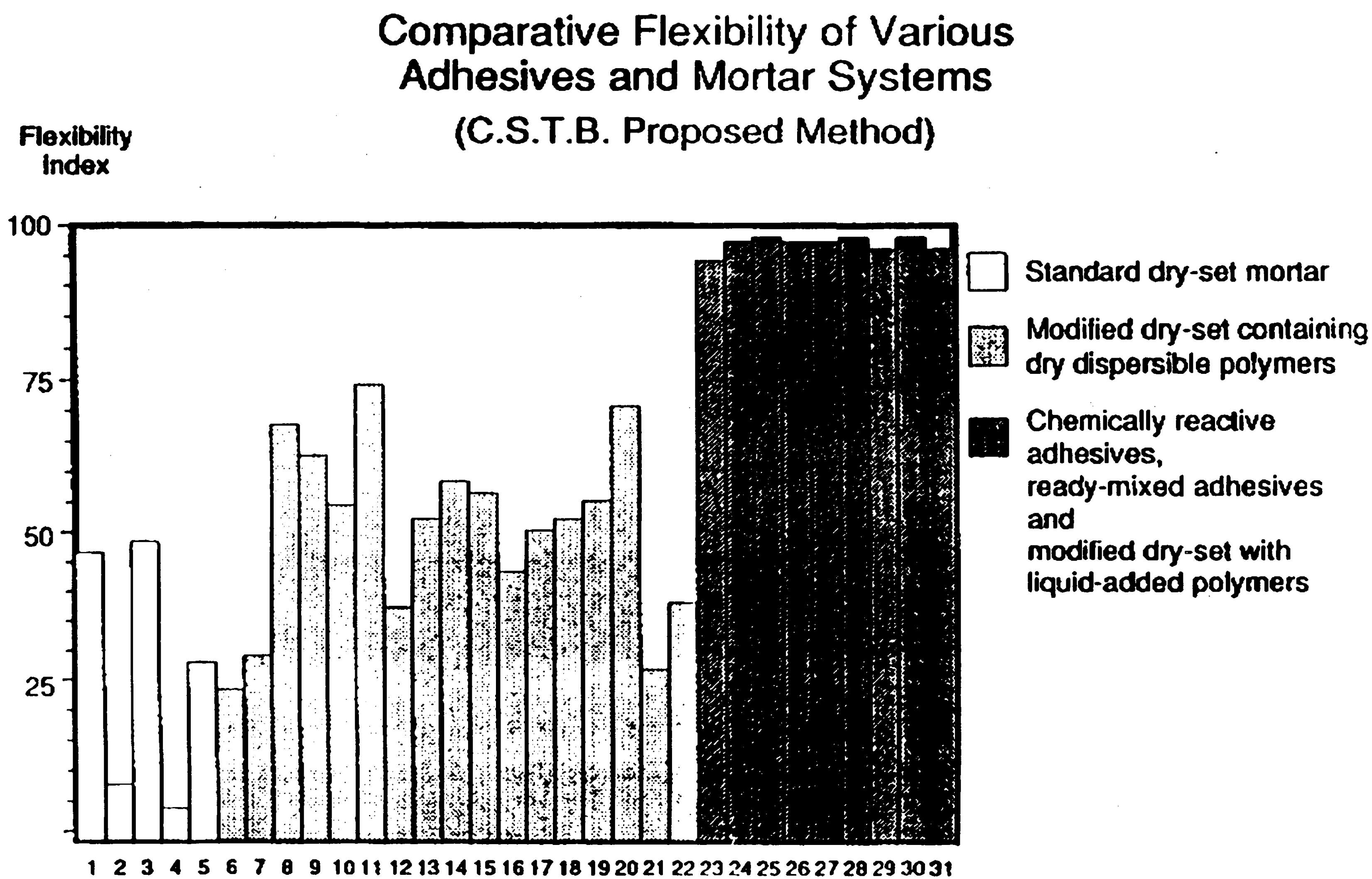
However, this is not true with liquid-added "polymer milk" systems, even when large amounts of polymers are used. Bond strength tests were conducted in accordance with the UEAtc directive and the results were plotted on comparative graphs. When the test specimens were cured at room conditions or under dry heat (graphs 7 & 8), it became clear that in all cases, the bond strength increased proportionately with the addition of polymers. However, in the case of the specimens tested after water immersion (graph 9), it became evident that the bond strengths of the spray-dried polymer modified mortars decreased sharply with every increase in their polymer contents to the point where at 7% polymer (by weight), the recorded bond strength was below the minimum UEAtc standard requirement of 5 kg/cm^2 (71.5 psi). Note that dry-set mortars modified with liquid-added "polymer milk" exceeded the minimum requirements even with 12% polymer content by weight.

CONCLUSION

The poor water resistance of spray-dried polymer modified formulas containing a high percentage of polymers is now explicitly recognized by some of the manufacturers who clearly specify that their so-called "FLEXIBLE" mortars are not suitable for use in wet areas or for exterior installation. In contrast, latex Portland cement mortar systems which are modified by liquid-added "polymer milks" are definitely the materials to use, especially for **exterior** floor and wall installation since **they are water and frost resistant**. Furthermore their cost remains reasonable.

It is believed necessary to clarify and define properly the term "FLEXIBLE in order to protect the tile installer and ultimately the consumer against its improper use and the misleading advertisement by some dry-set mortar manufacturers. In summary, water dispersible spray-dried polymer modified

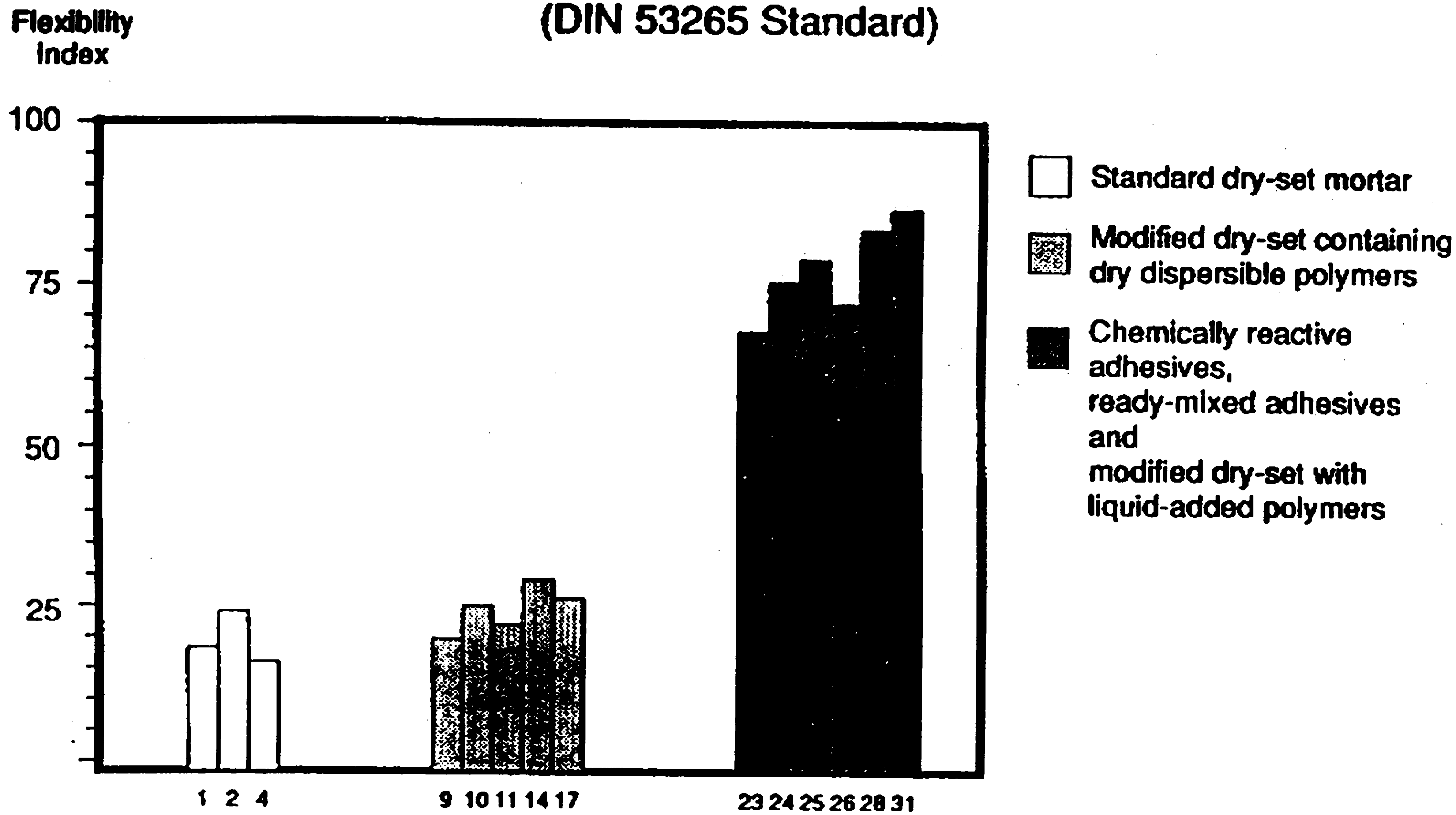
GRAPH 1


Comparative Flexibility of Various
Adhesives and Mortar Systems
(C.S.T.B. Proposed Method)
Flexibility Index
100
75
50
25
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31
Standard dry-set mortar
Modified dry-set containing dry dispersible polymers
Chemically reactive adhesives, ready-mixed adhesives and modified dry-set with liquid-added polymers

GRAPH 2

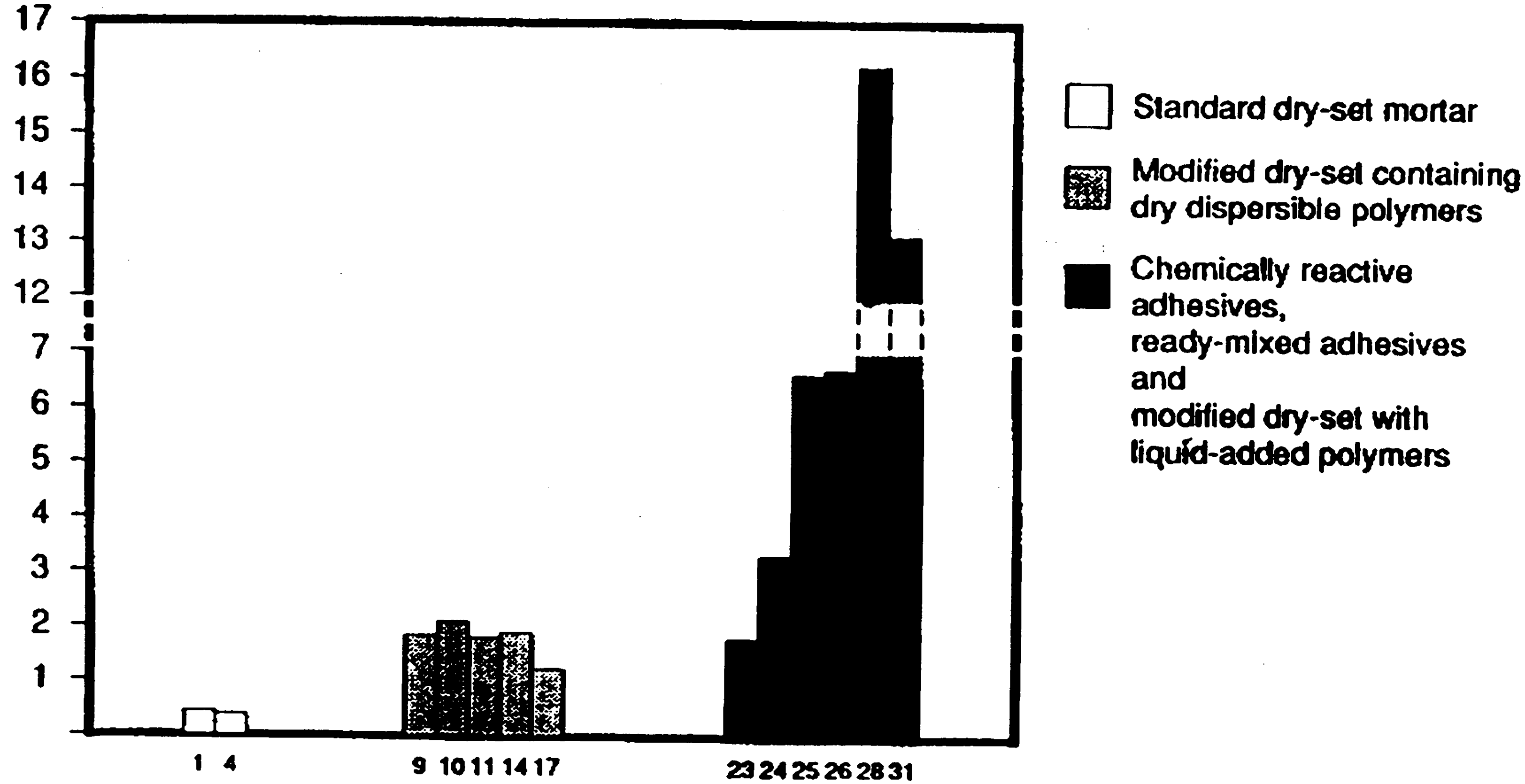
Comparative Flexibility of Various Adhesives and Mortar Systems

(DIN 53265 Standard)

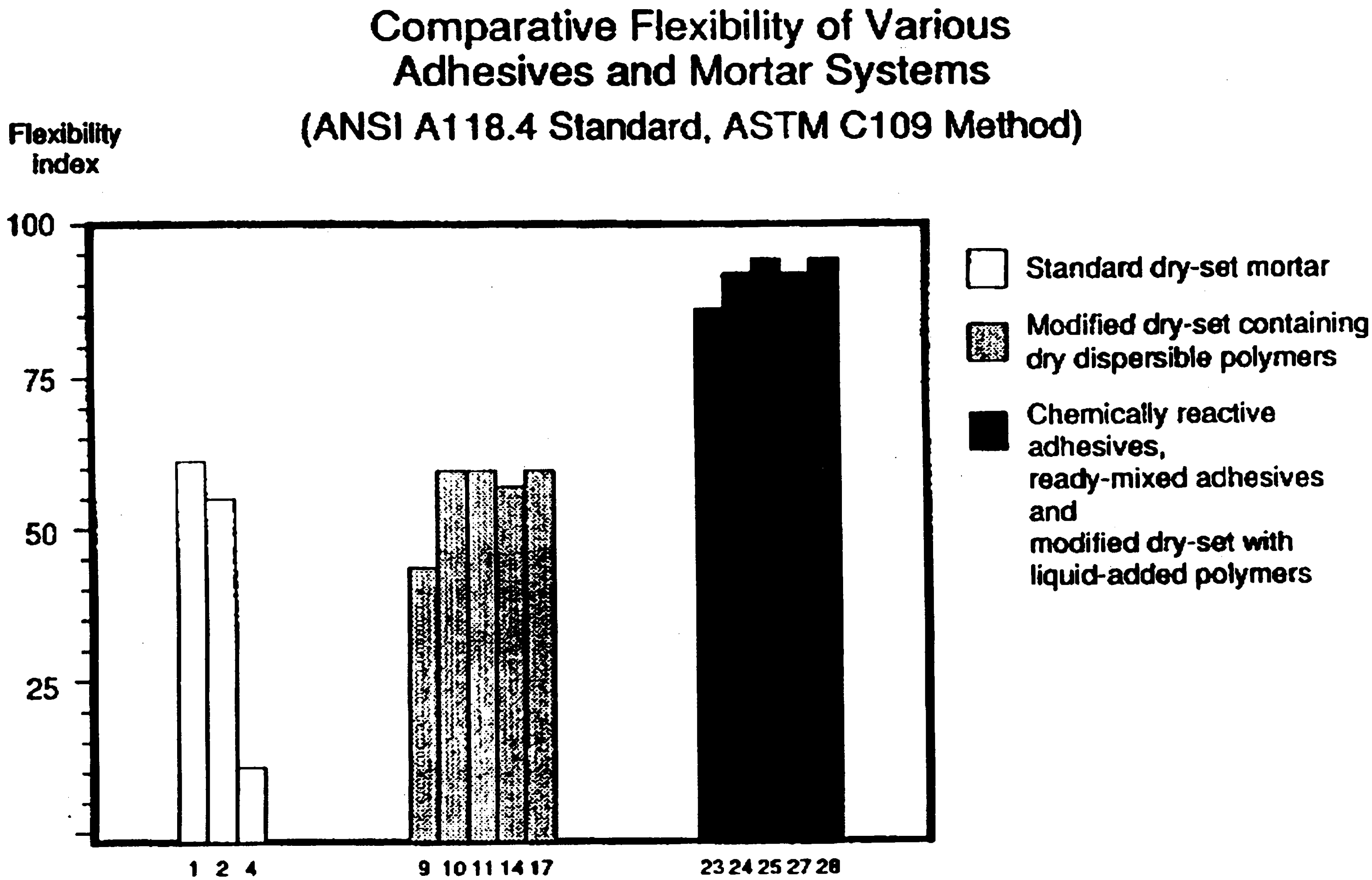


GRAPH 3

Comparative Flexibility of Various Adhesives and Mortar Systems
(UEAtc Directive)

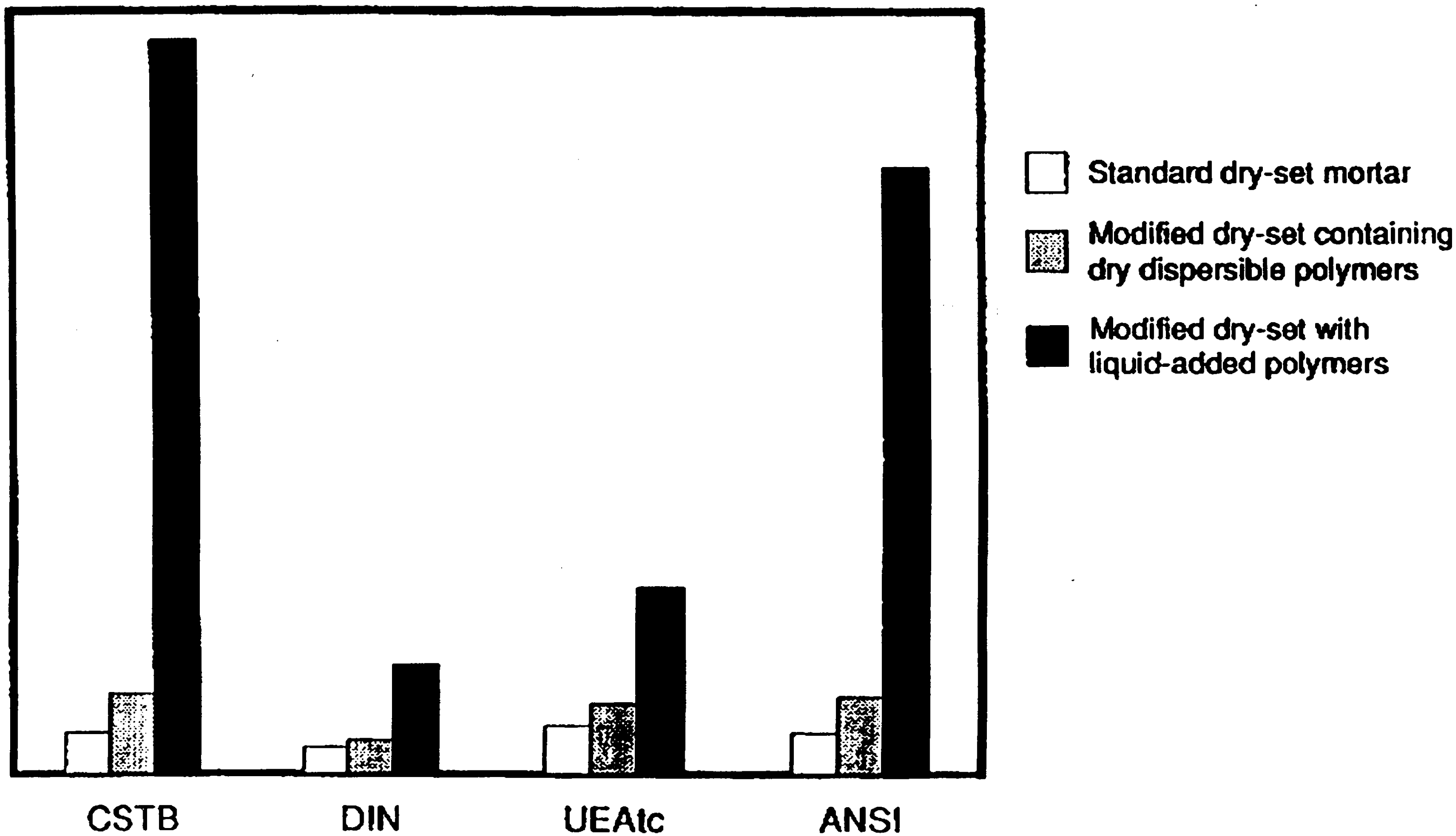


GRAPH 4


Comparative Flexibility of Various
Adhesives and Mortar Systems
(ANSI A118.4 Standard, ASTM C109 Method)
Flexibility index
100
75
50
25
1 2 4
9 10 11 14 17
23 24 25 27 28
Standard dry-set mortar
Modified dry-set containing dry dispersible polymers
Chemically reactive adhesives, ready-mixed adhesives and modified dry-set with liquid-added polymers

GRAPH 5

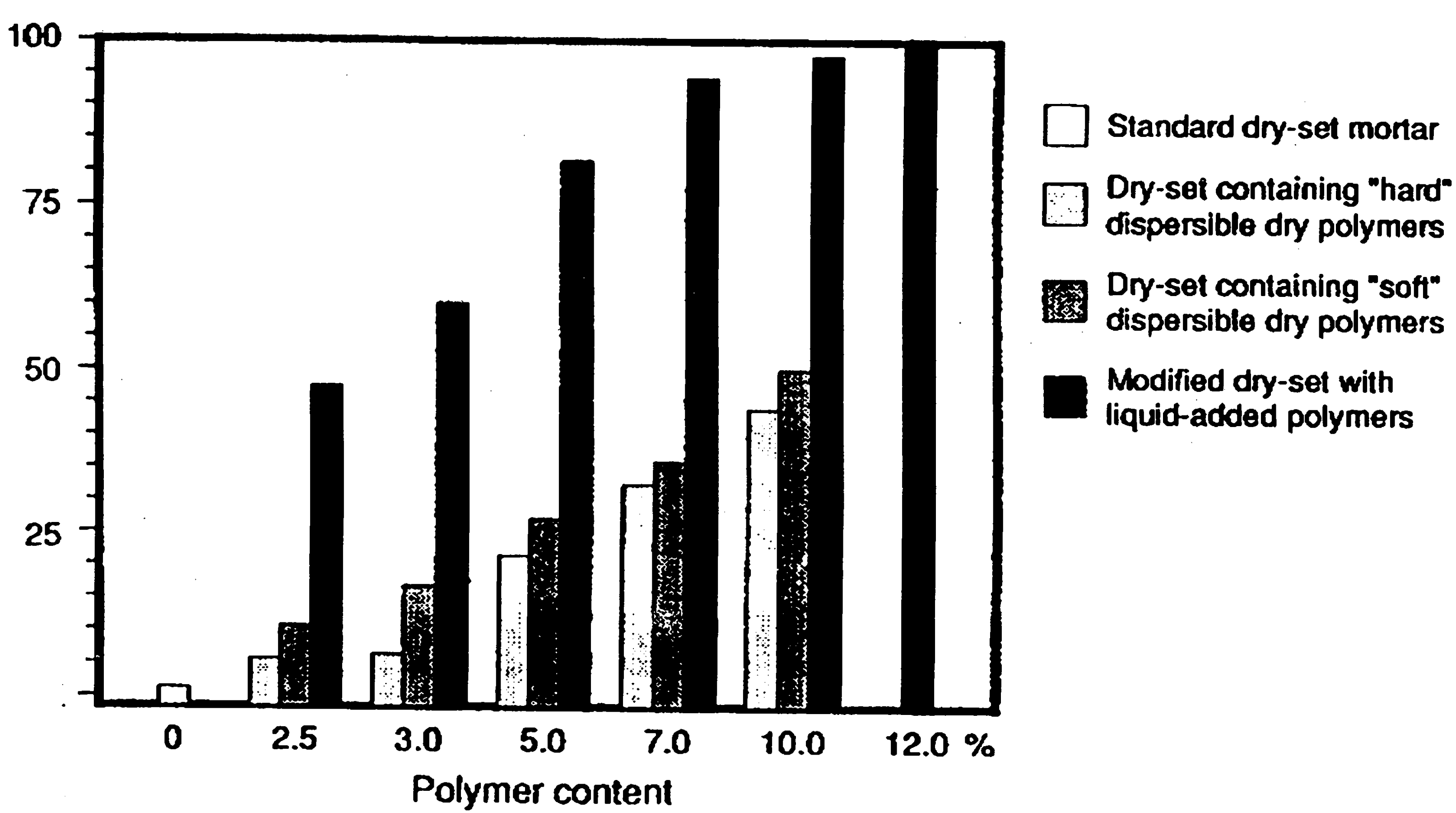
Comparative Flexibility of Mortars According to Various Test Methods



GRAPH 6

Comparative Flexibility of Mortars in Relation to Their Polymer Content

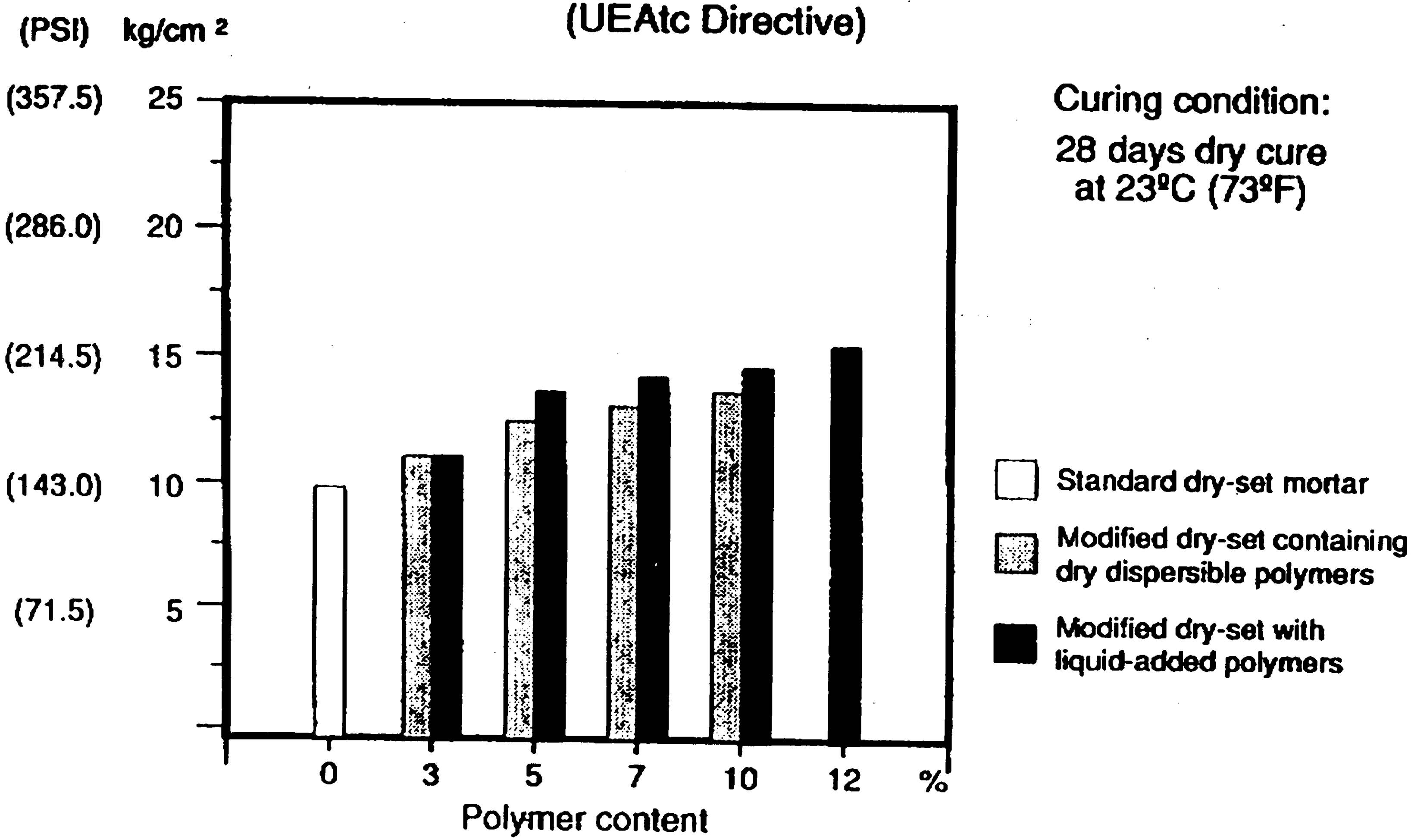
(C.S.T.B. Proposed Method)



GRAPH 7

Comparative Mortar to Concrete Shear Strength in Relation to the Mortar's Polymer Content

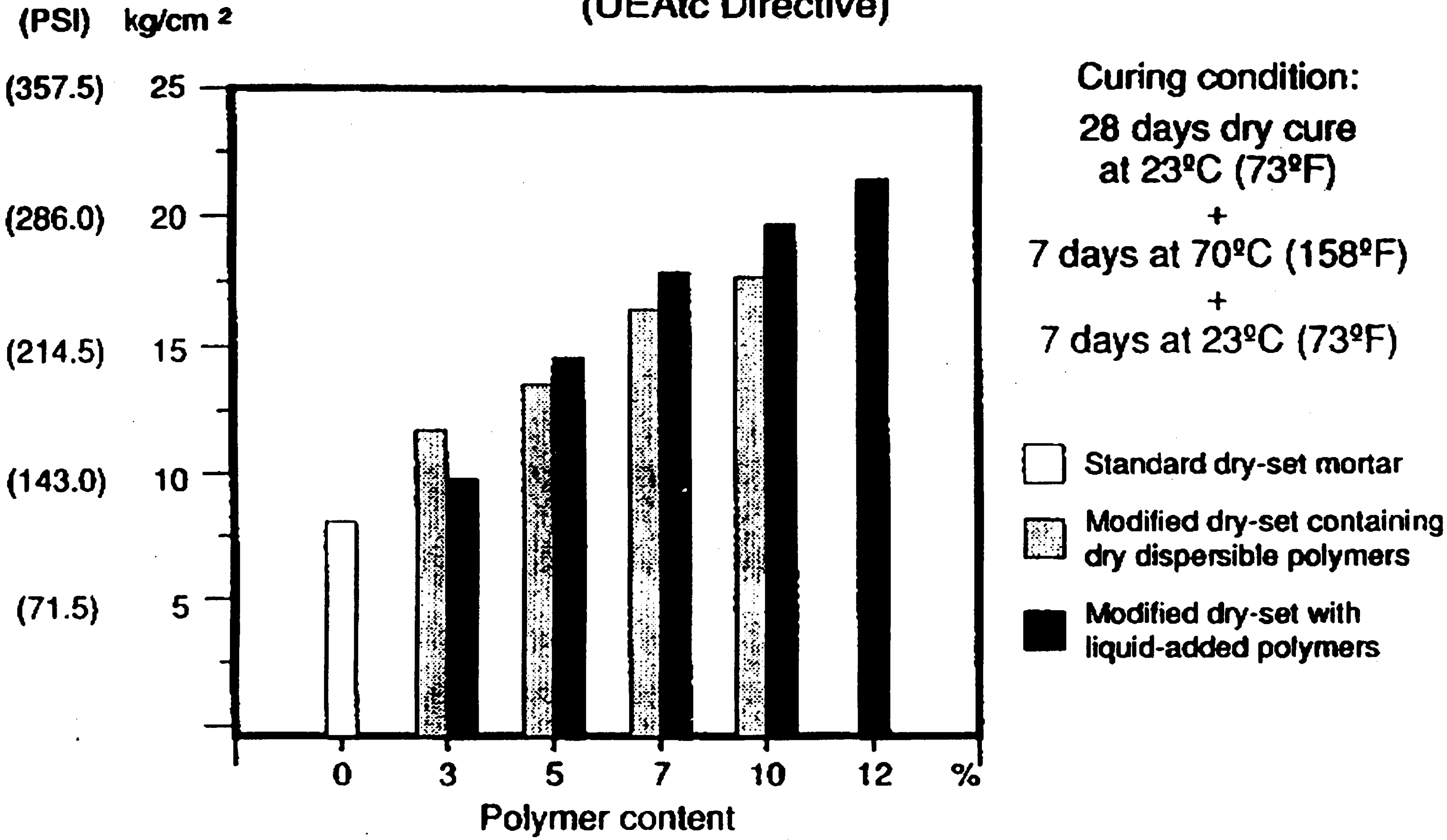
(UEAtc Directive)



GRAPH 8

Comparative Mortar to Concrete Shear Strength in Relation to the Mortar's Polymer Content

(UEAtc Directive)



GRAPH 9

Comparative Mortar to Concrete Shear Strength in Relation to the Mortar's Polymer Content

(UEAtc Directive)

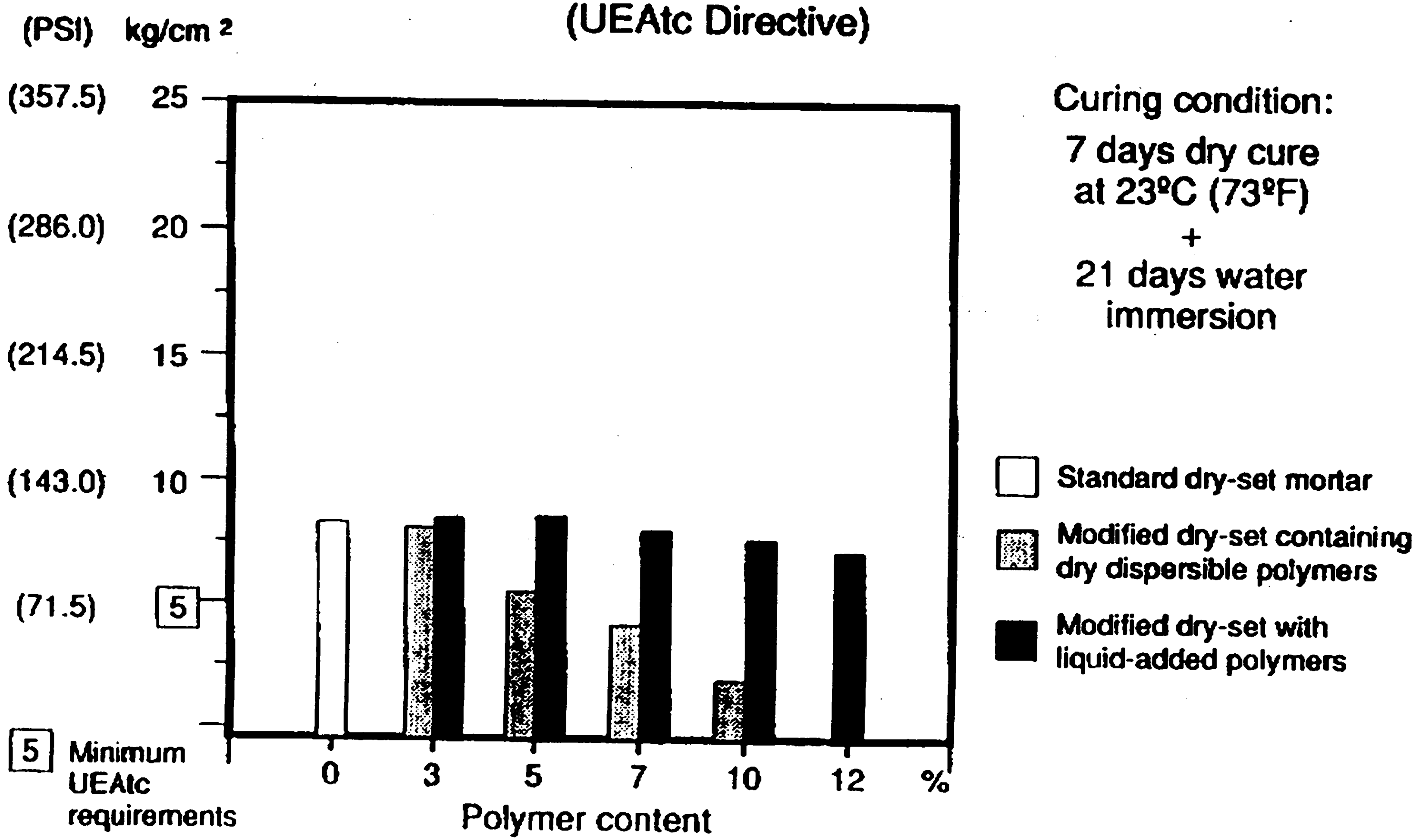
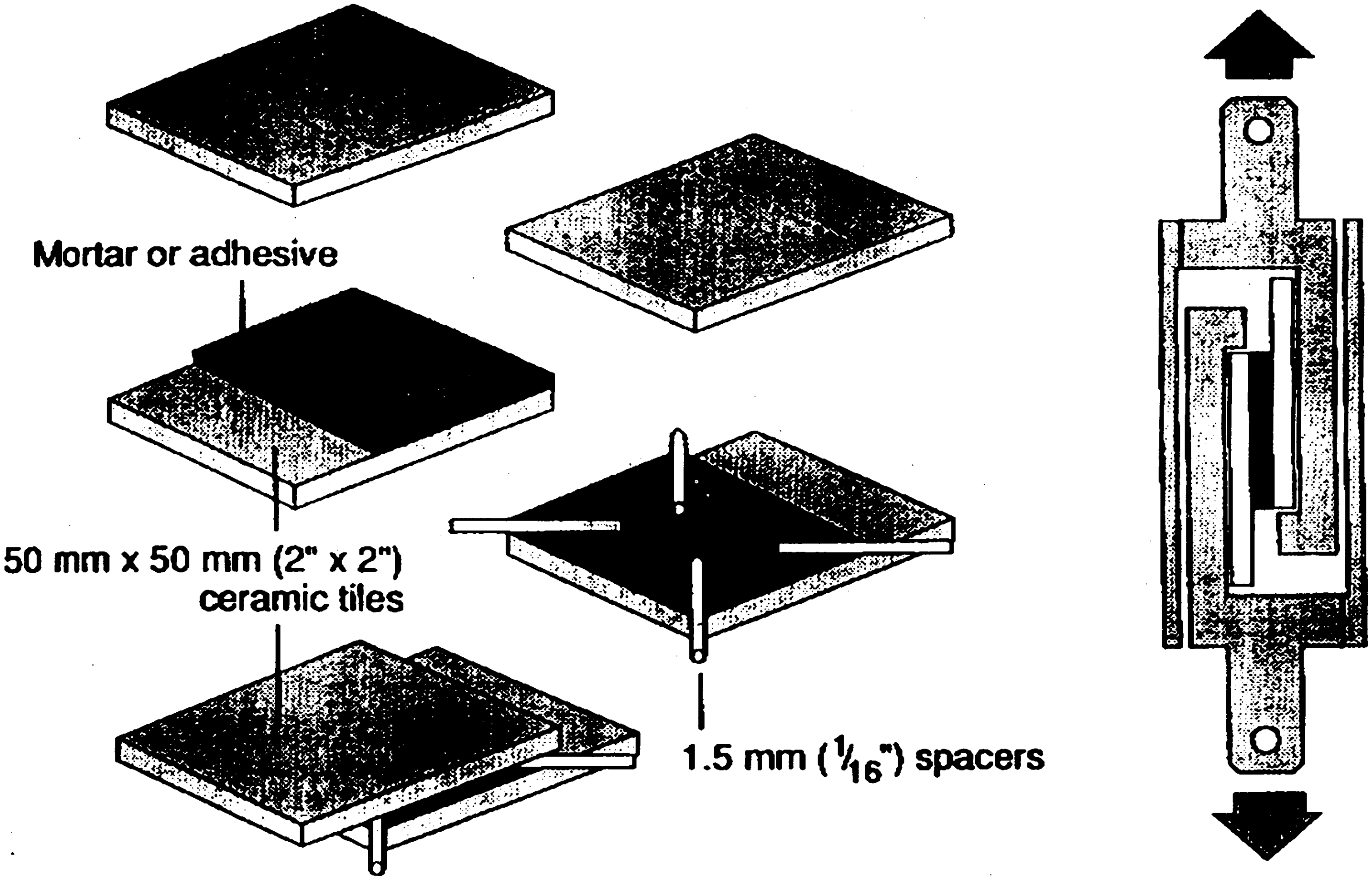
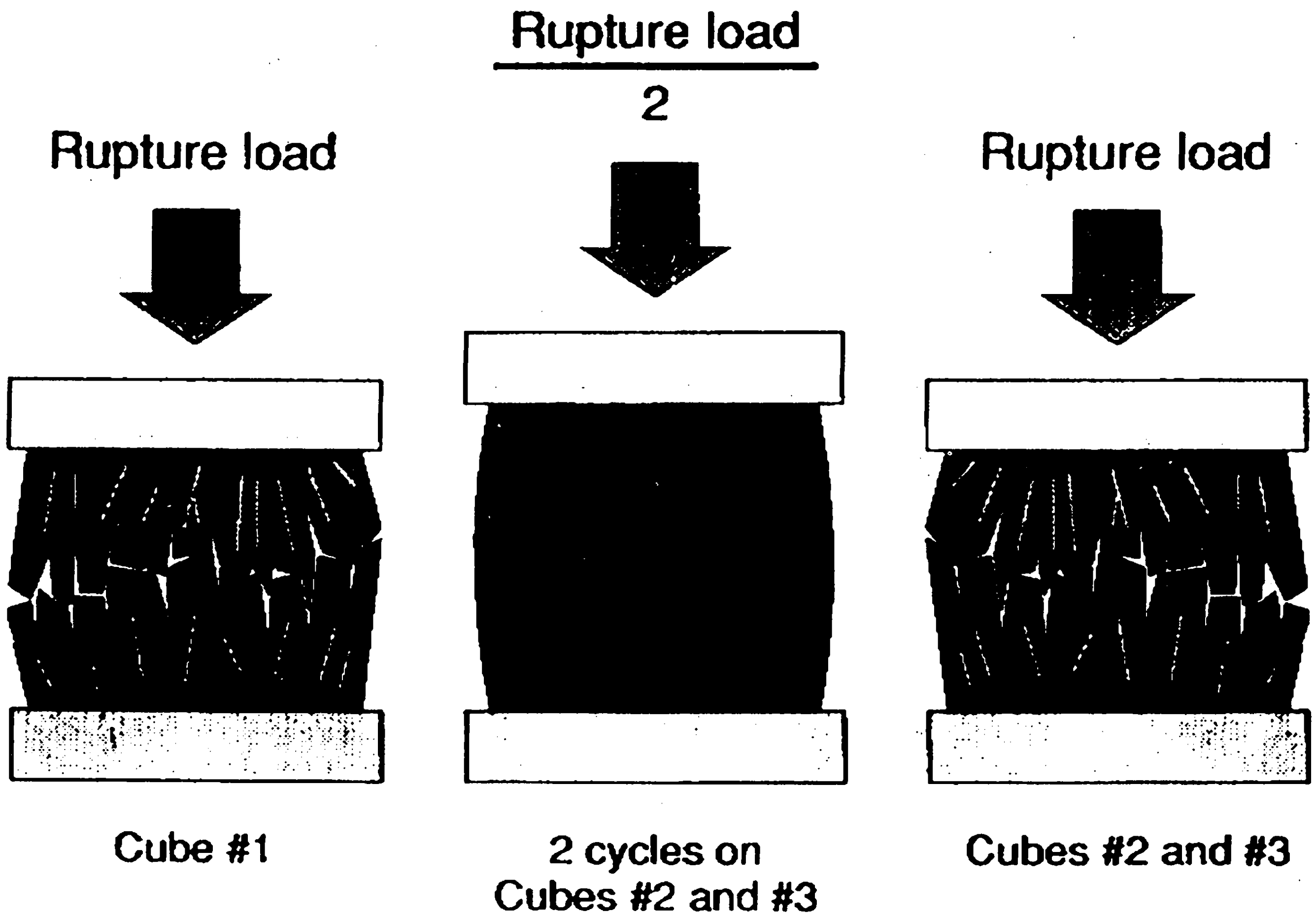


FIGURE 1



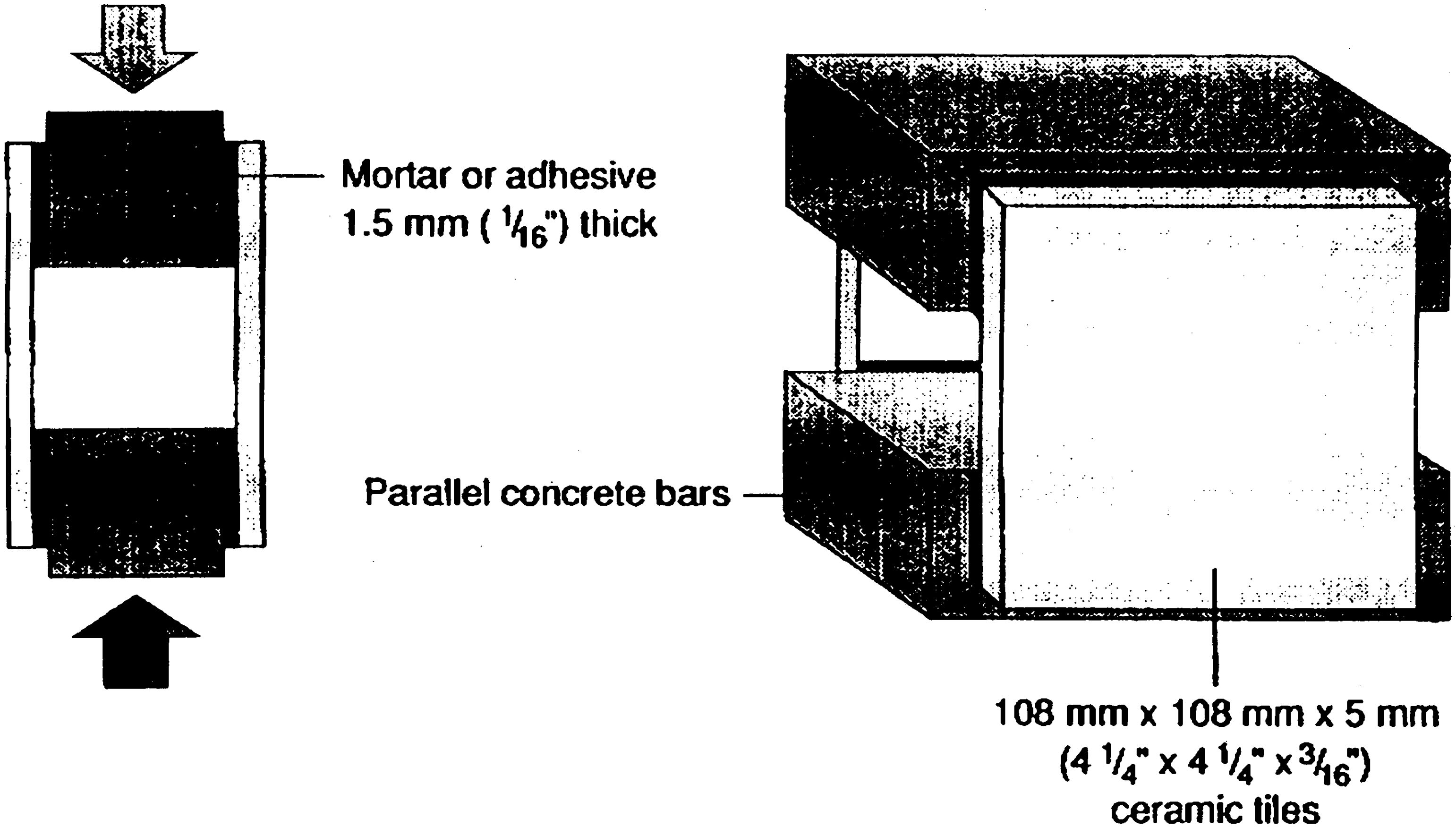
DIN 53265 Standard Test

FIGURE 2



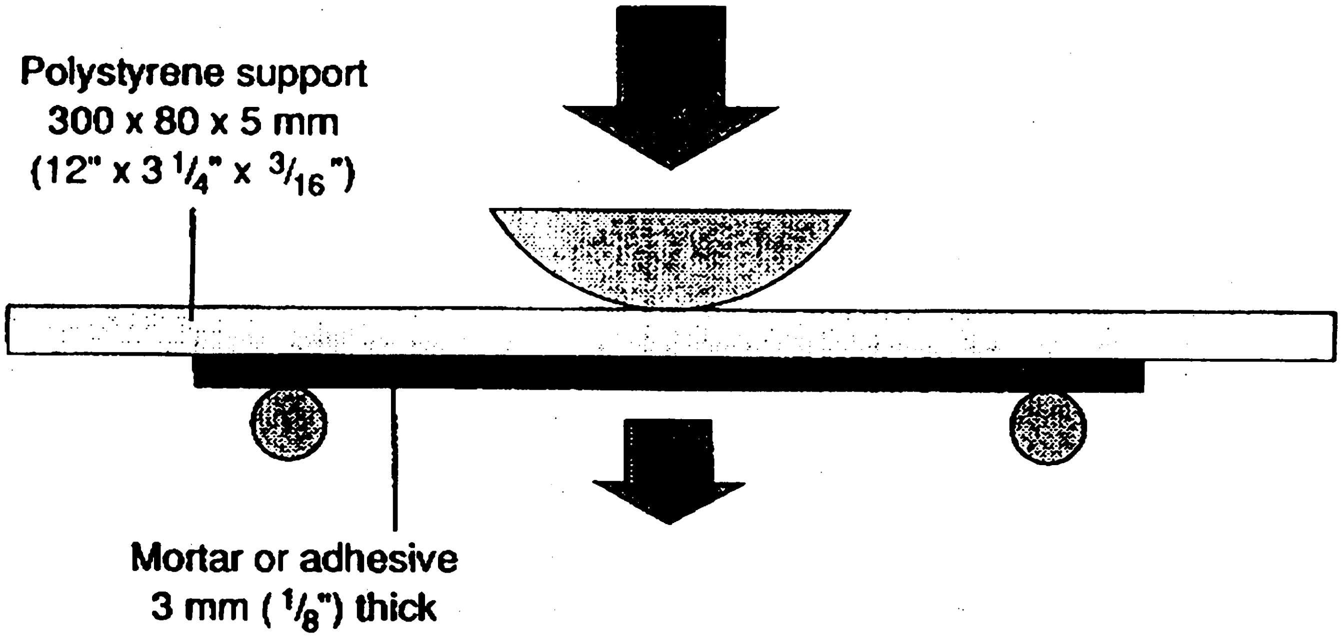
ANSI A118.4 Standard
(ASTM C109 Method)

FIGURE 3



EUAtc Directive 1979

FIGURE 4



C.S.T.B. Proposed Test