DEFORMABILITY AND WATER RESISTANCE OF C1 AND C2 ADHESIVES ACCORDING TO EN 12004 AND EN 12002

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ABSTRACT

The new European standard EN 12004 has created two main classes for cementitious tile adhesives: C1 and C2. C1 represents the standard tile adhesives, whereas C2 defines tile adhesives with increased requirements for tensile adhesion strength. The tensile adhesion strength is determined according to EN 1348.

Concerning deformability, EN 12004 specifies no requirements. EN 12002 describes a test to measure deformability, but does not require any additional specification.

The C1 and C2 specifications cannot be fulfilled without addition of polymers to the cementitious mortar. Two procedures may be used for this purpose: addition of a polymer dispersion to the premixed cementitious dry mix or incorporation of a redispersible polymer powder in the dry mix. The second way represents the modern dry mix mortars for the thinbed application technique, the importance of which is constantly growing.

The working mechanism of the incorporated polymers is the formation of polymer bridges in the hydrated mortar. By this, the cement matrix is reinforced, which leads to a better adhesion to difficult substrates and a better deformability of the hydrated mortar.

This gain in flexibility allows the tile adhesive to endure shear stresses, caused e.g. by shrinking substrates or by thermal expansion without damage.

There are several possibilities to measure this deformability:

- *Transverse deformation according to EN 12002*
- *Deformation according to DIN 18156/3*
- *Shear resistance and deformation according to EN 1324*
- *Tensile adhesion strength (70°C) according to EN 1348*

Extended test series delivered a good correlation between deformation according to EN 12002 and the tensile adhesion strength after heat treatment.

In order to minimise the drop of tensile adhesion strength after water immersion, several types of copolymers were tested.

Their influence on deformability according to EN 12002 and tensile adhesion strength according to EN 1348 was investigated.

1. INTRODUCTION

Nowadays, almost all tile applications require polymer modified dry-mix mortars in order to meet today's state-of-the art technical requirements concerning workability, efficiency and durability. The observable trend to high-quality "Porcelain" tiles with very poor water absorption (< 0,1 %) and to larger tile formats demands adhesives that allow a sure and durable fixation of these materials.

The classic tile adhesive consists of a simple composition of cement and sand. The mixture of both materials is applied in the thick-bed method. By modifying these mortars with cellulose ethers, workability and water retention are significantly improved, so that they can be applied by the thin-bed technique. This provides a high gain in productivity to the tiler.

However, the described tile adhesives will adhere poorly to many of the substrates found in the modern construction industry (e.g. polystyrene panels, wood panels, non absorbing substrates such as old tiles etc.).

Cementitious mortars are very hard and brittle materials, but many applications demand flexible, deformable mortars. In these cases, the modification of cementitious mortars with polymers becomes a must. In dry-mix mortars, the two binder systems, namely the mineral binder cement, and the polymer binder redispersible powder (RDP; spray dried dispersion), are ideal partners. Their incorporation in dry-mix mortars results in outstanding synergistic properties and characteristics which cannot be achieved by either of the binders alone.

Flexible tile adhesive mortars offer very good adhesion to all types of substrates with a high degree of deformation capability. Such tile adhesives can therefore be used universally. They offer high application and function safety as well as a long-term durability and reliability for all tile formats, tile materials and substrates.

Typical examples for application areas of these flexible, multi-purpose and high quality ceramic tile adhesives are:

- bonding of tiles on floor-heating systems, or where tile surfaces are exposed to heat (e.g. heating-up by solar energy),
- mounting tiles on tiles
- fixing tiles on difficult substrates like gypsum backgrounds, cement fibre boards, water proofing membranes, wood, thermal and sound insulation panels, light weight concrete blocks, etc.

The question arises, how to classify tile adhesives in relation to their mechanical properties and technical performances.

2. STANDARDISATION AND CLASSIFICATION

The new European standard EN 12004 classifies ceramic tile adhesives concerning their chemical composition and their mechanical properties. These classes are namely cementitious adhesives (C), dispersion adhesives (D) and reaction resin adhesives (R). In this paper, only cementitious adhesives are subject of consideration. The classification of the cementitious adhesives in relation to their mechanical requirements is shown in table 1:

Class	Tensile adhesion strength [N/mm²] acc. to EN 1348	Open time [N/mm²] acc. to EN 1346, after 10 min bedding time	Open time [N/mm²] acc. to EN 1346, after 20 min bedding time	Open time [N/mm²] acc. to EN 1346, after 30 min bedding time	Tensile adhesion strength [N/mm²] acc. to EN 1348; test after 24 h storage at standard conditions	Slip resistance [mm] acc. to EN 1308
C1	≥ 0,5		≥ 0,5			
C1E	≥ 0,5			≥ 0,5		
C1T	≥ 0,5		≥ 0,5			≤ 0,5
C1F	≥ 0,5	≥ 0,5			≥ 0,5	
C1ET	≥ 0,5			≥ 0,5		≤ 0,5
C1FT	≥ 0,5	≥ 0,5			≥ 0,5	≤ 0,5
C2	≥ 1,0		≥ 0,5			
C2E	≥ 1,0			≥ 0,5		
C2T	≥ 1,0		≥ 0,5			≤ 0,5
C2F	≥ 1,0	≥ 0,5			≥ 0,5	
C2ET	≥ 1,0			≥ 0,5		≤ 0,5
C2FT	≥ 1,0	≥ 0,5			≥ 0,5	≤ 0,5

Table1: classification of cementitious tile adhesives acc. to EN 12004.

As can be seen, the main differentiation is done by the tensile adhesion strength acc. EN 1348. For class C1, a tensile adhesion strength of at least 0,5 N/mm² after the four different conditionings is required, for class C2, the minimum limit is of 1,0 N/mm². The four conditionings (acc. to EN 1348) are given below

- 28 d sc

- 7 d sc + 21 d water immersion

- 14 d sc + 14 d 70 °C + 1 d sc

- 7 d sc + 21 d water immersion + 25 cycles freeze/thaw

where "d" represents days and "sc" stands for standard conditions (23 ± 2 °C / 50 ± 5 % r.h.).

In practice, 3 classes of tile adhesives prevail:

Standard, Flexible and Highly flexible. The distinction between one another depends on the amount of redispersible powder contained in the formulation.

The "Standard" tile adhesives can be sub-classified as follows:

- **Very simple standard tile adhesives**, which do not contain any polymer binder in the form of redispersible powder. They do not meet the new European standards. Such tile adhesives with a purely mechanical bonding by anchoring to the tile surface or substrate can only be used for fixing small, porous tiles onto porous, dimensionally stable, solid and strong mineral substrates, such as concrete, base coat render or masonry without shrinkage or movement of the substrate. Being exposed to higher temperatures or frost, means a high risk of damages.

- **Standard tile adhesives with improved adhesive bond strength** by addition of 1-3 % of redispersible powder on total dry mix. These types of tile adhesives generally meet the requirements for C1. They can be used to lay large tiles on non-porous, dimensionally stable substrates.

Tile adhesives with higher amounts of polymer addition are classified as "Flexible". They meet in general the requirements for C2.

- **Flexible tile adhesives** are modified to a higher extent of redispersible powder in the range of 3-8 %. These types of tile adhesives can be used universally. They offer a much higher application and function safety as well as long-term durability and reliability for all sizes of tiles, tile materials and substrates.

- **Highly flexible tile adhesives** with polymer contents up to 25 % are products for special use, e.g. laying tiles on very fresh screeds, that will suffer a high amount of shrinkage.

Table 2 gives an overview of typical formulations for these different classes:

Typical formulations for ceramic tile adhesives				
Requirements/ component	Type			
	very simple standard	standard	flexible	highly flexible
Meets standard C1 or C2	no	yes	yes	yes
Portland cement CEM I 32,5 R	30 – 35 %			
Portland cement CEM I 42,5 R or CEM I 52,5		30 – 35 %	35 – 40 %	25 – 40 %
Silica sand (0,05 – 0,5 mm)	64,7 – 69,7 %	61,7 - 68,7 %	46,5 – 61,5 %	29,5 – 66,5 %
Cellulose ether	0,3 %	0,3 %	0,5 %	0,5 %
Redispersible powder	-	1 – 3 %	3 – 8 %	8 – 25 %
Special additives	-	-	0 – 5 %	0 – 5 %

Table 2: typical formulations for ceramic tile adhesives.

3. ADHESION

The adhesion of a tile adhesive is determined by a pull off test described in EN 1348. The tensile adhesion strength [N/mm²] is evaluated using stoneware tiles (acc. to EN 87) laid on concrete slabs conditioned in 4 different ways as described above.

For a class C1-tile adhesive, the most selective test is the adhesion after heat ageing. If the tile adhesive contains no redispersible powder, it will fail. An addition of 1-3 % of redispersible powder will make it pass this very important and critical test. The heat ageing test indicates whether a tile adhesive provides sufficient flexibility after curing. In relation to practical application the test assesses the capability of the material to compensate a certain level of strains resulting from different thermal expansion coefficients of the tiles and the substrate when exposed to higher temperatures. Figure 1 shows the effect of polymer (copolymer of vinyl-acetate and ethylene, TG = 10 °C) on the adhesive bond strength after heat ageing with different tiles.

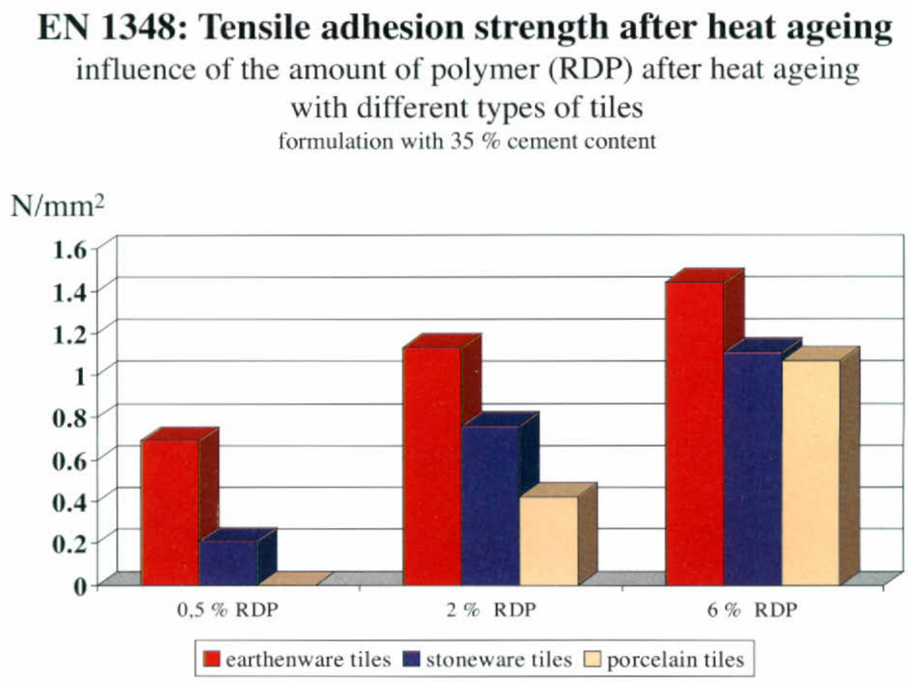

Figure 1: influence of the amount of polymer upon tensile adhesive strength after heat ageing with different types of tiles.

A class C2-tile adhesive requires much more formulation effort because of the stringent tensile strength requirements (> 1,0 N/mm²). In order to pass the test after standard conditions and heat ageing, an addition of redispersible powder in the range of 3-8 % is generally sufficient. The most critical tests in case of C2 are those after water immersion and freeze/thaw-cycles. Under these conditions, the dominant binder system is the cement. Generally, the cement content in C2-formulations has to be increased up to about 40 %. This means, that at a constant level of redispersible powder the polymer/cement-ratio is decreased, thus the flexibility of the tile adhesive is lowered.

It has further to be considered that a sufficiently high percentage of polymer is required if hard-to-bond tiles, like the non-porous (so-called fully vitrified) porcelain tiles or glass tiles with their extremely low water absorption have to be fixed with a cementitious ceramic tile adhesive. In this case, a mechanical fixation or anchoring of the cementitious mortar on the non-porous tile surface will not take place, so that the adhesion has to be provided by the polymer. In practice, flexible ceramic tile adhesives are recommended and successfully used to fix fully vitrified or porcelain tiles. These high quality flexible ceramic tile adhesives are modified with at least 4 % of a suitable redispersible powder. Figure 2 shows the tensile adhesive strength in relation to the polymer content at different substrates. Figure 3 illustrates the correlation of tensile adhesive strength with the content of polymer and the type of tiles used.

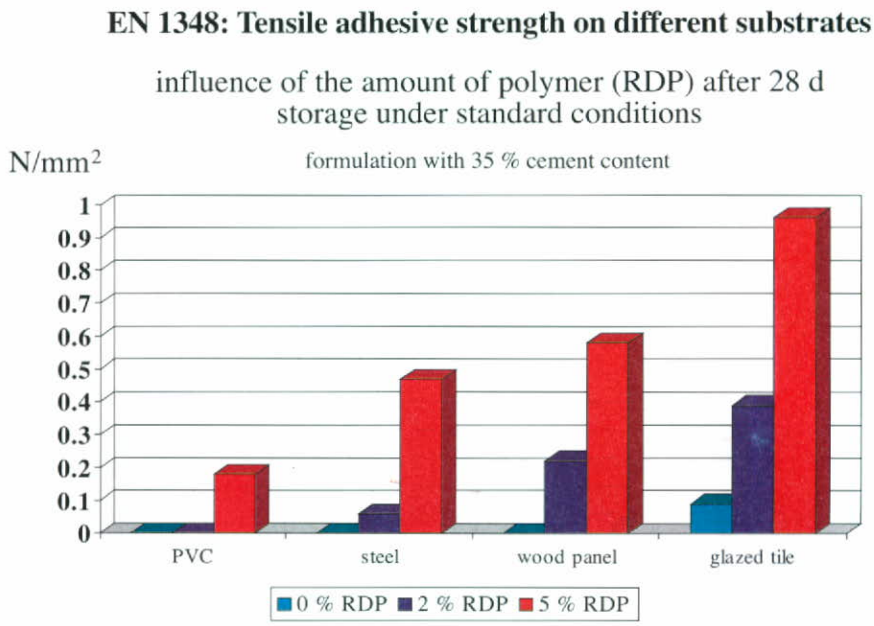

Figure 2: tensile adhesive strength correlated with polymer content and kind of substrates.

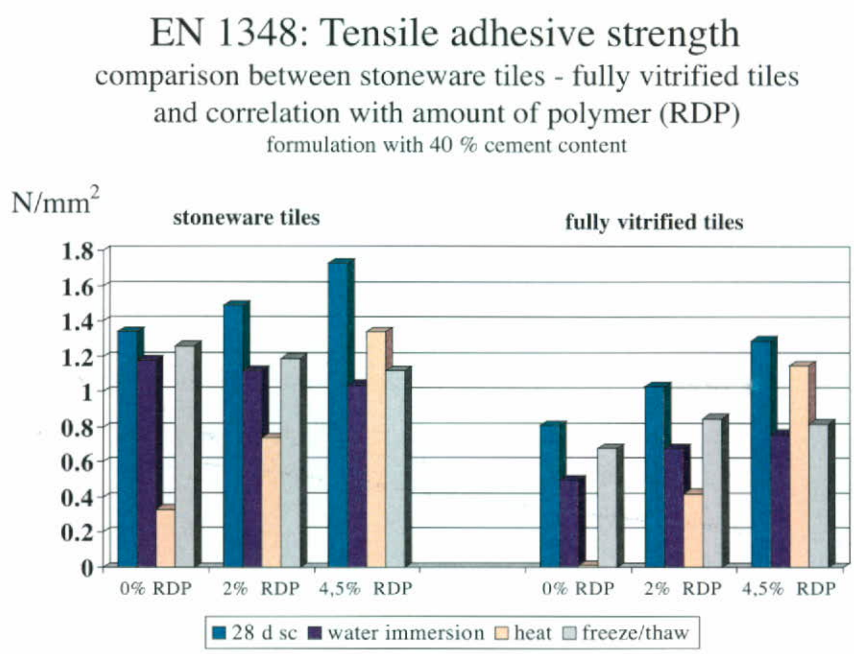

Figure 3: tensile adhesive strength correlated with type of tiles and amount of polymer used.

Conclusions from figure 3 concerning tensile adhesive strength after heat curing:

- Rising adhesion with increasing proportion of redispersible powder; Secure fixation can only be achieved with addition of redispersible powder.
- No employment of redispersible powder: Stoneware tiles as used in EN 1348 show still weak bonding; No adhesion at fully vitrified tiles.

It can further be concluded, that for the stoneware tiles, the tensile adhesion strength after sc and heat treatment improves with an increasing amount of polymer. This observation does not apply to the conditionings water immersion and freeze/thaw. This is explained by the fact, that for the stoneware tiles, the cement can still anchor to their surface. During the water conditioning, the hydration of the cement continues, which leads to a weakening of the cement matrix. The polymer cannot compensate this effect.

In case of the fully vitrified tiles, the adhesion drops dramatically at all treatments, but rises significantly with an increasing polymer amount. For this type of tiles, the mechanical anchoring of the cement to the tiles has obviously lost its effectiveness and the adhesion is dominated by the incorporated polymer, even after water immersion and freeze/thaw conditions.

This means, that a C1-classified tile adhesive according to EN 12004 (2 % RDP) in combination with fully vitrified tiles performs below the C1-level and even a C2-tile adhesive (4,5 % RDP) drops down to the C1-level. Expressed in practical terms: Only a highly polymer modified tile adhesive offers a secure and durable fixation of this type of tiles.

4. DEFORMABILITY OF A TILE ADHESIVE

The deformability of a tile adhesive is one of its most important properties to ensure long-term durability. In 1997, the European standard EN 12002 on the transversal deformation of tile adhesives was published. The fact that the classification in EN 12004 does not provide values for this deformation leads to the problem how to measure the deformability of a tile adhesive and how to correlate it with other mechanical requirements for tile adhesives.

In some European countries, national approaches to define "flexible" tile adhesives exist. In France, the CSTB (Centre Scientifique et Technique du Bâtiment) has created a new class called „C2S" which combines the requirements for a C2-tile adhesive acc. to EN 12004 with a deformation of 3 mm minimum acc. to EN 12002.

In Germany, the manufacturers of tile adhesives and the tilers have agreed on a „Richtlinie für Flexmörtel" (Guide on flexible mortars), which defines flexible mortars and their area of application. They combine the requirements of C2 acc. to EN 12004 with an additional deformation of at least 2,5 mm acc. to EN 12002.

However, the European Committee for Standardisation is preparing a new version of EN 12002, where it is discussed, to introduce also minimum requirements for deformation. The present draft provides two classes: S1 for deformation > 2,5 mm and S2 for deformation > 5 mm.

5. HOW TO DETERMINE THE DEFORMABILITY OF A TILE ADHESIVE?

Though the flexibility of a tile adhesive is considered as an important property for practice conditions, the methodology of determining it, especially in a reproducible way, still awaits definition.

It has to be kept in mind, that the most important factor for all methods to determine the deformability of a cementitious tile adhesive is the degree of hydration of the incorporated cement. Therefore care has to be taken that the degree of hydration of the cement is complete. But this is not the case for most of the storage conditions that are prescribed in the standards. Especially in the case of EN 12002, the climate conditions during the storage influences in a dramatic way the results of deformation as will be shown below.

What possibilities do exist to measure flexibility?

Besides EN 12002, there are other methods to determine the deformability of a tile adhesive:

- shear resistance and deformation acc. to UEAtc / DIN 18156/3
- shear resistance and deformation acc. to EN 1324
- tensile adhesion strength after heat conditioning acc. to EN 1348

SHEAR RESISTANCE AND DEFORMATION ACC. TO UEATC / DIN 18156/3:

This test was developed in the 1970's according to a theory of Mr. Wesseling, who did a lot of investigation on deformability of mortars. The test is carried out as follows: two mortar bars are connected with two stoneware tiles and a tile adhesive of 3 mm thickness. After storage of the specimen, a force is applied on the mortar bars and shear strength and deformation until mortar failure are monitored and recorded. Figure 4 shows the scheme of the test configuration.

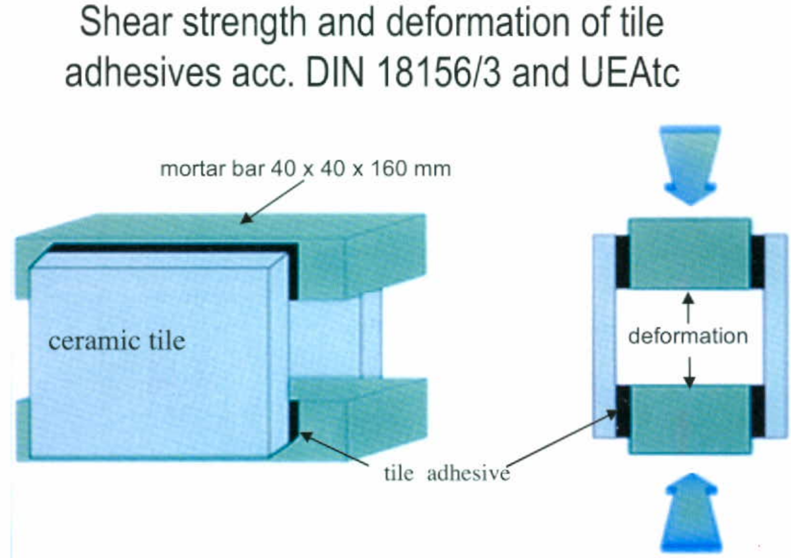

Figure 4: shear test acc. to UEAtc / DIN 18156/3, scheme of test configuration.

A test series was carried out with formulations containing 35 % of Portland cement and different amounts of a redispersible powder (copolymer of vinylacetate and ethylene, TG 10 °C). In parallel, the same formulations were tested acc. to EN 1348 in order to find out whether and eventually how deformation, shear resistance and adhesive bond strength correlate. The storing conditions were identical for all specimens:

14 d sc + 14 d 70 °C + 1 d sc

Figure 5 shows the results for deformation of the test acc. to DIN 18156/3. The results of the test for shear resistance acc. to DIN 18156/3 compared with the tensile adhesive strength determined acc. to EN 1348 are illustrated in figure 6.

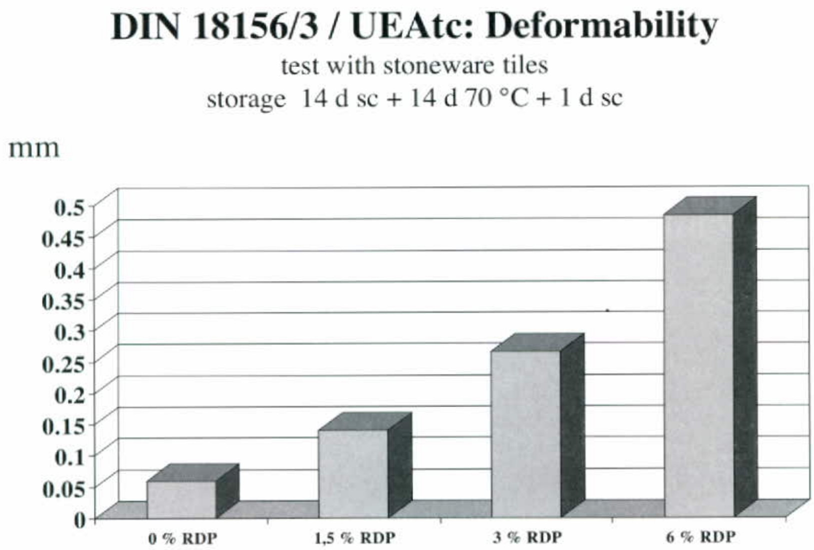

Figure 5: deformation acc. to DIN 18156/3 / UEAtc vs. polymer content.

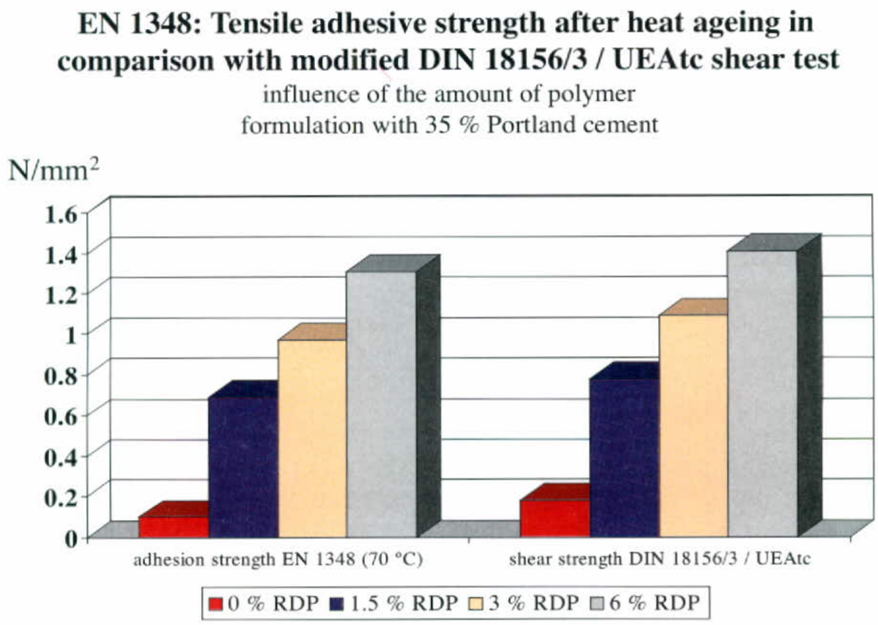

Figure 6: shear resistance acc. to DIN 18156/3 compared with the tensile adhesive strength acc. to EN 1348.

As a first and obvious result of this test series it can be seen from the graph:

the higher the amount of polymer in the formulation, the higher is the deformation ability of the tile adhesive. This is very important to know for the practical use, where the tile adhesive often has to absorb enormous shear stresses, e.g. in outdoor applications where the sun may heat the floor up to 80 °C and a sudden rain cools it instantly down to 20 °C. Only a polymer modified tile adhesive is able to absorb such stresses without cracking or loss of adhesion to the tiles.

A second finding is, that the tested tile adhesives show almost identical profiles for shear resistance and tensile adhesive strength, both plotted versus RDP percentage. Augmenting the polymer content increases the values for adhesion and shear strength. This shows, that the tensile adhesive strength after heat conditioning correlates to a high degree with the shear strength and the deformability acc. to DIN 18156/3. It can therefore be concluded, that a high value for tensile adhesive strength after heat storage indicates high flexibility of a tile adhesive.

SHEAR RESISTANCE ACC. TO EN 1324:

This shear test normally applies to dispersion based ready-to-use tile adhesives, but it may also be utilized for cementitious systems. For this purpose the test was modified: the mortar is applied with a notched trowel (6 x 6 x 6 mm) instead of the pattern as described in EN 1324. Otherwise the mortar bed would be too thin and the mortar therefore risks drying too fast on the tiles (water absorption 15 %), without having the possibility to hydrate correctly. Figure 8 shows results for shear resistance and deformation of a cementitious tile adhesive containing 40 % Portland cement. The content of polymer (copolymer of vinylacetate and ethylene, TG 10 °C) was varied from 0 % to 6 %.

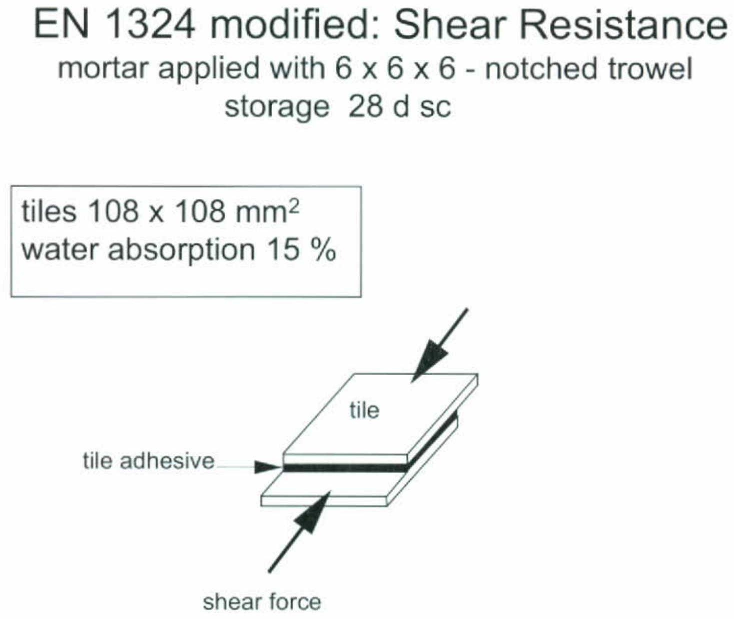

Figure 7: specimen acc. to EN 1324.

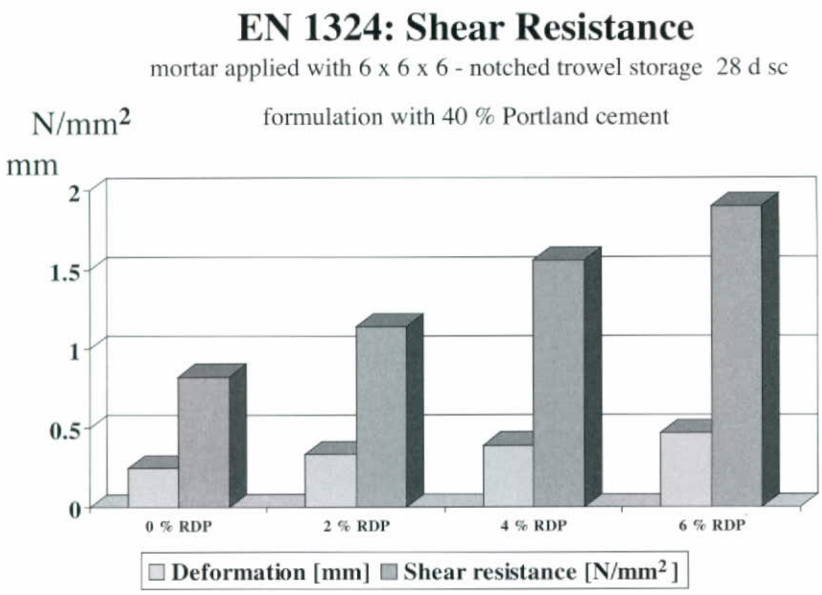

Figure 8: modified shear test acc. to EN 1324 for a cementitious tile adhesive.

Concerning shear resistance, there is a clear influence of the amount of redispersible powder used. The values increase with rising polymer content. At a first glance, there seems to be a slight increase in deformability with greater polymer portions in the formulation. Since the differences are rather small and taking reproducibility into account, they have to be interpreted as non- significant.

Conclusion: The modified shear test acc. to EN 1324 is a convenient method to measure the shear resistance of a cementitious tile adhesive and to obtain a good indication for its capacity of strain and shock absorption capability.

TRANSVERSAL DEFORMATION ACC. TO EN 12002:

When this method to determine the deformability of cementitious tile adhesives was introduced, it was intended to provide a simple test that overcomes the difficult and time consuming preparation of specimens acc. to DIN 18156/3 / UEAtc, which often caused poor reproducibility.

The preparation of test specimens acc. to EN 12002 is indeed fast and easy, but as the specimens often show curvature and torsion after drying, reproducibility is again a problem. For this reason, Mapei elaborated a modified procedure for the preparation of specimens. The following results were obtained with specimens prepared after the Mapei modification of EN 12002, but with one exception: The mortar was not densified on the shock table as proposed by Mapei.

As already mentioned above, a very important factor for the deformation is the storage of the specimens. Figure 9 demonstrates the effect of different storage conditions on deformation for a formulation containing 30 % cement and 6 % of redispersible powder.

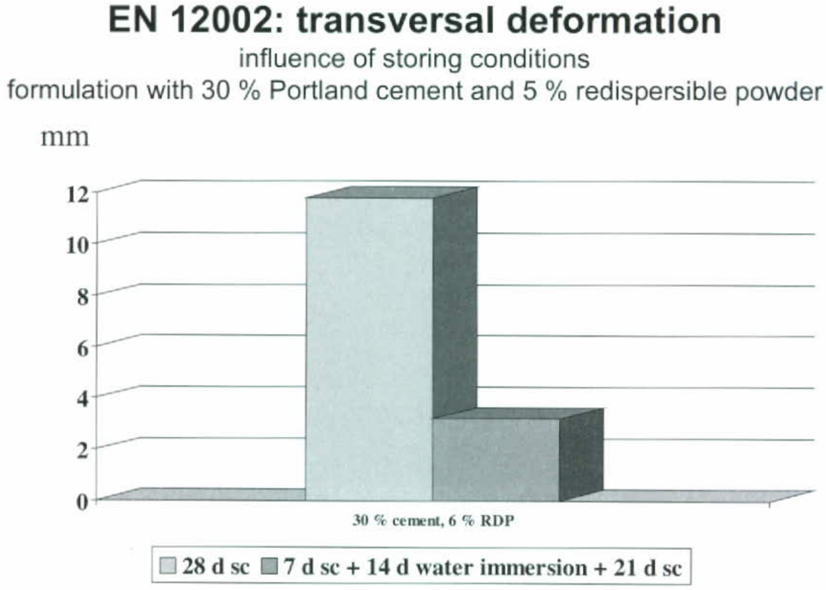

Figure 9: influence of storage conditions on deformation.

The results of figure 9 show very clearly, that in the case of the storage under standard conditions the hydration of the cement is very poor, thus leading to a very high value of deformation. If the specimen is stored for 14 days in water, the cement is nearly fully hydrated, resulting in a deformation that is only 25 % as high as after storing under standard conditions. This proves the necessity of a water storage instead of storage in a plastic bag as described in EN 12002 to ensure the full hydration of the cement.

In a further study, the influence of the type of polymer on the deformability and on the tensile adhesive strength of tile adhesives was investigated. Four different copolymers were synthesised with the same TG of 10 °C. The four different systems are:

polymer 1 = copolymer of vinylacetate and ethylene

polymer 2 = copolymer of methylmethacrylate and butylacrylate

polymer 3 = copolymer of styreneacrylate

polymer 4 = copolymer of vinylacetate and VeoVa

The polymers were added to the tile adhesive as dispersions. The polymer content was varied from 0 % to 6 % of the total dry mix. The formulation contained 30 % of Portland cement. The results for the deformation of these tile adhesives are given in figure 10. The figures 11 and 12 show the results for tensile adhesive strength acc. to EN 1348 after heat conditioning and water immersion.

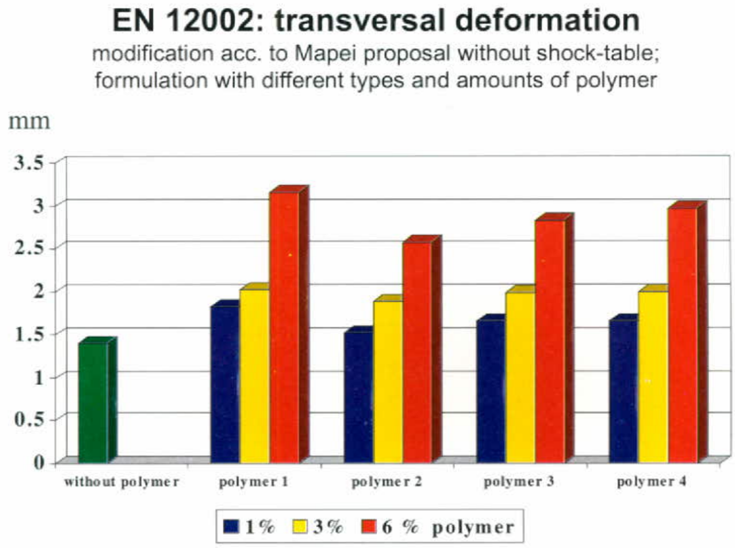

Figure 10: influence of different types of polymers on deformation.

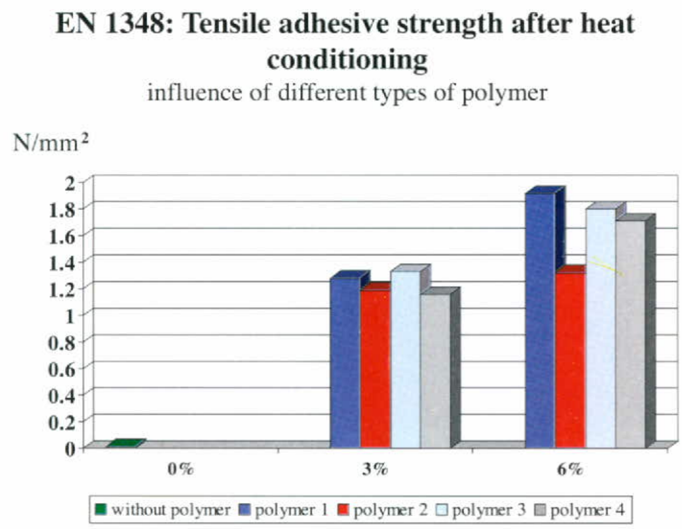

Figure 11: influence of type of polymer on tensile adhesive strength after heat conditioning.

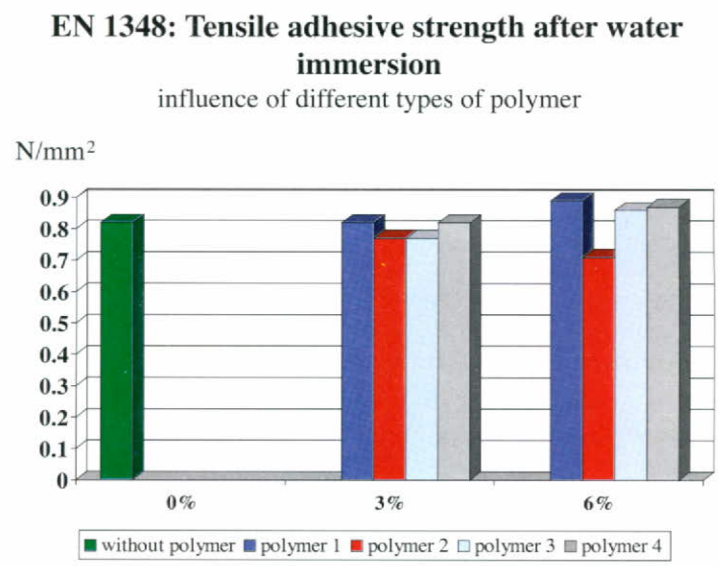

Figure 12: influence of type of polymer on tensile adhesive strength after water immersion.

Results:

- Increasing amounts of polymer result in higher deformability acc. to EN 12002 and higher tensile adhesive strength acc. to EN 1348 after heat conditioning. Again, an excellent correlation between deformability and adhesive strength after heat treatment exists. The only exception is polymer 2, which performs lower than the others, especially after heat treatment.
- Without addition of polymer, the mortar fails to meet the adhesion test after heat conditioning.
- Concerning tensile adhesive strength after water immersion, no type of copolymer showed an improvement. The measured values remain at the level of the non-modified mortar. The reason is, that the cement continues to hydrate under these test conditions (water immersion). Consequently, this process anticipates the expected effect of the polymer, as discussed earlier (see 3. Adhesion).

6. CONCLUSION

Under real life conditions, cementitious tile adhesives are subjected to stresses between tiles and substrate. These stresses between substrate and tiles may be caused by shrinkage of fresh concrete, vibrations or different expansions of the tiles and the substrate (e.g. at solar exposure) due to their different thermal expansion coefficients. The tile adhesive has to endure all these stresses in order to guarantee a stable fixation of the tiles over time. All test results, reported on in this study, suggest that this stability can only be achieved with a sufficiently high polymer modified mortar.

The heat ageing test acc. to EN 1348 imitates the stresses between substrate and tiles and is therefore a good indicator for the flexibility of a tile adhesive. This finding is in excellent correlation with the results of the deformation tests acc. to DIN 18156/3 and EN 12002.

The most critical issue to be respected in all the deformation tests is the storage of the specimen. The hydration of the mortar must be almost completed prior to these tests. Otherwise a comparison between different mortars is not possible. It has to mentioned that the storing conditions in EN 12002 do not allow an appropriate determination of the flexibility of a tile adhesive.

Concerning the tensile adhesive strength acc. to EN 1348, the water immersion is the most difficult criterion for C2 tile adhesives to pass. Because of the progressing hydration of the cement with a swelling of the cement particles during water immersion, the cement matrix is weakened. This behaviour dominates the tensile adhesive strength.

The role of the polymer as additional binder becomes evident also under these test conditions, when the test is applied to fully vitrified tiles, where the cement as only binder cannot assure a stable adhesion.