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Long-term performance of redispersible powders in mortars

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Abstract

Long-term performance of polymer-modified mortars in outdoor and indoor exposure was examined over 10 years. Three redispersible powders based on different copolymers were used. Over the 10-year period the vinylacetate–ethylene (VAE) copolymer market standard as well as styrene–acrylics (SA) and an ethylene–vinylchloride–vinyllaurate (terpolymer) gave stable adhesive, flexural and compressive strength. The terpolymer also showed long-term performance in hydrophobicity over a 5-year period in stuccos. According to scanning electron microscopy (SEM), the morphology of the polymers in the mortars does not change over the 10-year period. © 2001 Elsevier Science Ltd. All rights reserved.

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1. Introduction

The use of polymers as a modifier for mortars and concrete is well known. If a thermoplastic polymer is used, the mortars are called polymer cement concrete (PCC).

PCC can be either a one-component system (one part) or a two-component system (two parts). In the case of a two-part system, the thermoplastic polymer is admixed in the form of a latex or dispersion with the dry components (cement, aggregates) at the job site. The one-part system already contains the polymer admixture in the form of a dry, redispersible powder.

Such redispersible powders are spray-dried dispersions. When these powders are mixed with water, or with mixing water in a mortar, they produce stable dispersions with properties comparable to the original dispersion. The art of the chemists, dealing with the product group, is that the powders redisperse only once and not later when a hardened mortar becomes wet again.

An overview on the properties of redispersible powders is given elsewhere. [1,2]

Emulsions and redispersible powders are thermoplastics and form films with high tensile and adhesion strength on different materials. They act as a second binder in the mortar, in combination with the inorganic cement. Both the cement and polymer constitute their respective benefits. The pronounced increase in adhesion strength of mortars on different substrates is the main reason for the widespread use of PCC in construction systems. Cheap logistics, no preservation, security at the job site and the reduced waste disposal of containers are additional success factors for one-part PCC.

Not much is reported in the literature about long-term performance of one-part PCC with redispersible powders, especially with respect to the comparison of different co- and ter-polymers. Kolonko [3] describes the influence of long-term performance of emulsion-based PCC. Preliminary results of this study have been presented in the International Congress of Polymers in Concrete [4].

In this paper, we present our investigations on the long-term performance of one-part PCC with redispersible powders over 10 years time in a typical test formulation 1 according to DIN 1164. As a comparison, we monitored the performance of the same mortars in standard climate conditions. We primarily measured adhesion strength, but included flexural and compressive strengths. We tested redispersible powders based on vinylacetate–ethylene (VAE), which is the standard polymer base of the market. We also examined a styrene–acrylic (SA)-based product. This polymer base is very popular for emulsions used in the construction field for two-part PCC. Third, we studied a terpolymer of ethylene–vinylchloride–vinyllaurate, which is very popular for EIF system renderings, stuccos and grouts, offering, in addition to

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binding power inherent to all these systems, a hydrophobic effect in modified mortars and stuccos.

To underpin the results of the mechanical tests, we took scanning electron microscope (SEM) photographs to show the condition of the polymers after 10 years outdoor exposure.

A typical stucco formulation was chosen to determine the long-term performance in hydrophobicity. The hydrophobic effect reduces the water uptake of the stucco, which is a real benefit in outdoor application.

The testing was carried out with modified and unmodified cement mortars. Details of the mixes are shown in the experimental section (Formulations 1 and 2). To see the influence of different redispersible powders, we tested the polymers at a constant 0.15 resin:cement ratio. The air content was adjusted to a similar level by using a defoamer.

2. Experimental

In all experiments, a Portland cement CEM l 32.5 R and a sand mixture according to DIN EN 196 was used.

Redispersible powders used are the following:

Vinnapas RE 545Z/vinylacetate–ethylene powder with $T_G = -7°C$,
Vinnapas RI 551Z/ethylene–vinylchlorid–vinyllaurate powder with $T_G = 1°C$,
Vinnapas LL 512 (styrene/acrylic powder with $T_G = 20°C$.
All powders are produced by Wacker Polymer Systems
T_G = glass transition temperature

Defoamer Agitan P801 (Münzing)

CEM l 32.5 R (g)	25.00
Sand mixture (g)	71.25
Vinnapas powder (g)	3.25
Defoamer Agitan P 801 (g)	0.50

The water:cement ratio was 0.5.

2.1. Formulation 2

This formulation is a basic formulation for a typical stucco.

Sand 0.2–0.7 mm	400.0
Sand 0.1–0.4 mm (g)	250.0
Sand 1–1.8 mm (g)	50.0
Sand flower 10 000 mesh (g)	80.0
Chinafill F1 (g)	20.0
Titandioxid Kronos 2056 (g)	40.0
White cement Dyckerhoff (g)	40.0
Hydrated lime (g)	80.0
Starchether Amylotex 8100 (g)	0.2
Vinnapas RI 551Z (g)	0 to 60
Water (g)	220.0

The stucco was mixed with water for 3 min in a standard Tony mixer and then applied. The water absorption was measured according to DIN 52 617.

2.2. Procedures

The Formulation 1 mortars were mixed in accordance with DIN EN 196 in a Tony mixer. The data concerning workability (air content, and slump characteristics), which are given in Table 1, have been measured according to DIN EN 196 / DIN 1060.

NC is the normal climate, 23°C/50% relative humidity (standard test condition according to ISO 554).

Two storage conditions were used:

Outdoor exposure: Exposition in the Burghausen (Germany, lat 48°N, long 15°E) outdoor station of Wacker-Chemie. The bars and slabs were placed facing south at a 45° inclination.
Indoor exposure NC

The test specimen for compressive and flexural strength were demoulded after 1 day in NC condition. In addition, all other specimens that were prepared were conditioned over one night in NC. Afterwards the outdoor and indoor exposure was started.

The mortars were tested at various ages for adhesion strength, compressive strength and flexural strength. The first measurement was done after 28 days, then after 1, 2, 3, 5 and 10 years. The specimens from the outdoor exposure were conditioned for 7 days in NC before testing to avoid accidentally different humidities or temperatures at the time of testing. This can be caused by a rain shower or extreme long periods of sunshine just before testing.

Compressive and flexural strengths have been measured according to DIN EN 196 with bars 160 × 40 × 40 mm. For each redispersible powder, five bars were always tested each time for compressive and flexural strength.

The adhesion bond was measured with samples where the mortar was applied with a trowel to a thickness of 10 mm on a concrete block (according to DIN 485 and DIN 18500). Before applying the mortar, the surface was sandblasted. No primer was used. The adhesion strength was measured according to DIN 18 156. The samples were core

Table 1
Workability

Formulation 1		Slump characteristics, cm	
	Air content, %	Without strokes	With strokes
Without polymer	5	10	16.5
Vinnapas RE 545Z	7	15	19
Vinnapas RI 551Z	7.5	10	12.5
Vinnapas LL 512	2.5	14.5	19

drilled through the mortar just into the substrate before testing. A steel disc was attached to the surface of the core using epoxy glue. The specimens were tested in direct tension at a load rate of 250N/s. For each value, five separate measurements were always done.

In the figures the results for the different tests are shown with the medium value and the general standard deviation is given in the headline of the figure.

SEM samples were prepared from broken material. From our experience over the last 15 years, this is the favorite sampling to get correct information about the morphology of the material. The outdoor exposed material showed a large amount of crystalline material had formed in the pores during storage. Therefore the surface of the samples were prepared with one drop of 0.1 M nitric acid for 5 min and cleaned with clear water. The nitric acid dissolves some of the crystalline material and the polymer domains become visible. As usual, the material was sputtered with gold and the measurements were made with a JEOL instrument.

3. Results

3.1. Adhesion strength

The modification of mortars with film forming thermoplastic materials, like emulsions or redispersible powders, considerably increases the adhesive bond strength to different substrates. This is the main reason for the widespread use of these products all over the world [5].

Figs. 1 and 2 demonstrate the increase of the adhesion by modification with redispersible powders in indoor and outdoor exposure. The unmodified mortar (blank) shows lower values than the modified mortars. Fig. 1 shows that in outdoor exposure, the adhesion bond strength increases during 10 years and that RE 545Z, a vinylacetate–ethylene product, showed the highest adhesion bond strength after 10 years. Initially all three polymer types have similar performance. The unmodified mortar also shows increasing adhesion bond strength over time in outdoor exposure. In indoor exposure the adhesive bond strength, as shown in Fig. 2, is not increased, but stays below 0.5 N/mm^2.

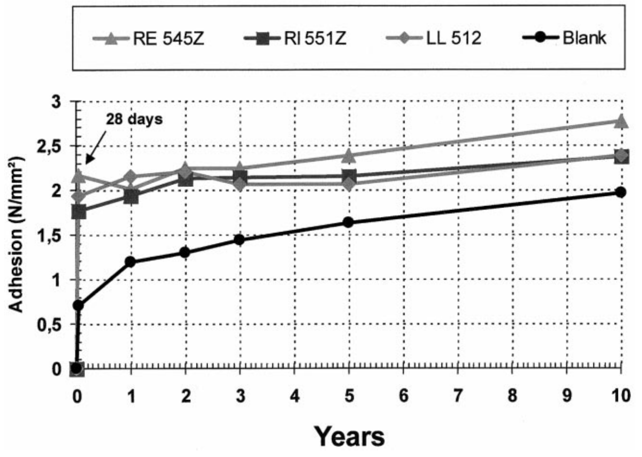

Fig. 1. Adhesion strength (N/mm^2); standard deviation about 10%. Formulation 1: outdoor exposure.

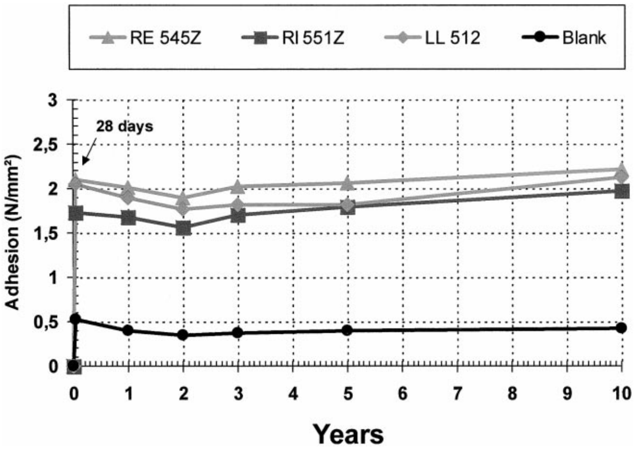

Fig. 2. Adhesion strength (N/mm^2); standard deviation about 10%. Formulation 1: indoor climate conditions.

This is in agreement with the theory of how a polymer acts in a mortar and shows the weakness of the unmodified mortar. In a thin layer of 10 mm, the water retention of the mortar is insufficient. The mortar has lost the water before the cement has fully reacted with the water to gain higher strength.

In PCC, the polymer acts as the binder bringing superior adhesion strength to the mortar and, even after 10 years, there is still an extra for the PCC. Although the unmodified mortar had sufficient time and water to fully hydrate in outdoor exposure the adhesion strength of the PCCs are 20–30% higher. Only limited water out of the air at 50% RH is available in the indoor climate and the big gap between the adhesion strength of PCC and the unmodified mortar remains constant over the 10 years.

All three redispersible powders show stable and high adhesion strength over the 10-year period regardless of exposure conditions.

3.2. Flexural strength

It is well documented that the flexural strength is increased by a polymer resin modification with an emulsion or a redispersible powder especially in early ages of the mortar. [2,6] The polymer is concentrated in the pore system of the hardened mortar and acts as reinforcement. Fig. 9, an SEM photograph, gives an example. The strength in tension of the polymer material is in the order of 7–10 N/mm^2; cement itself has tension strength only in the order of 1 N/mm^2 [1].

Figs. 3 and 4 demonstrate that the degree of hydration of the cement also plays an important role. Within 1 year in outdoor exposure, the flexural strength of the unmodified

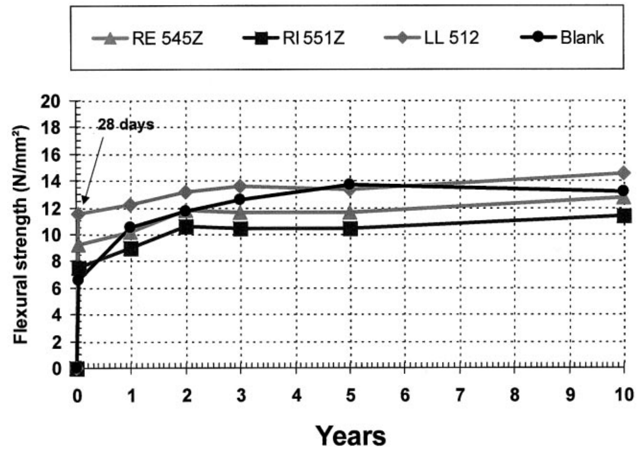

Fig. 3. Flexural strength (N/mm^2); standard deviation about 8%. Formulation 1: outdoor exposure.

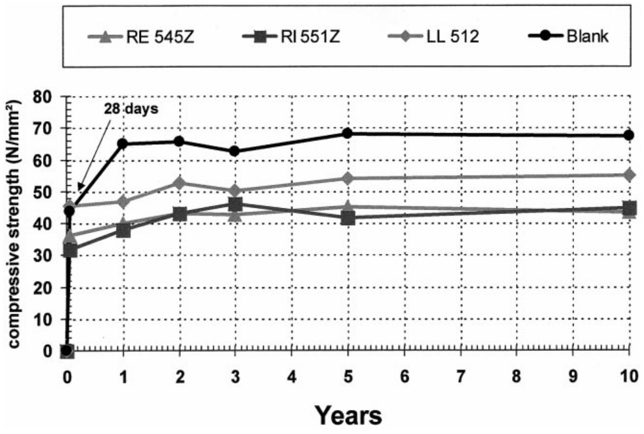

Fig. 5. Compressive strength (N/mm^2); standard deviation about 5%. Formulation 1: outdoor exposure.

mortar has nearly doubled compared to the 28-day value, and the flexural strength is slightly higher than the mortar modified with RE 545Z and RI 551Z.

In indoor climate, the unmodified mortar needs 10 years to reach the same performance as in outdoor conditioning after 1 year. We explain this as above by the different degrees of hydration of the cement. Due to the low water content of the air in indoor condition, it takes a long time to absorb water from the air at 50% RH.

The three PCCs modified with redispersible powders show stable results over the 10-year period regardless of exposure conditions.

3.3. Compressive strength

Compared with hydrated cement or the aggregates, the thermoplastic redispersible powders are very soft materials with low compressive strength. It has been shown that at the same water–cement ratio and comparable air content of the mortar, the modification of a mortar with a thermoplastic emulsion or a redispersible powder leads to a reduction of the compressive strength [2]. The compressive strength of a mortar is mainly influenced by the porosity of the system: the lower the porosity, the higher the compressive strength [6, 7]. To a certain degree, related to compressive strength, the polymer modification can be calculated as additional porosity. Having this in mind, Figs. 5 and 6 can easily be explained. In outdoor and indoor exposure, the unmodified mortar always shows the highest compressive strength. In outdoor exposure the unmodified mortars gets sufficient additional water to fully hydrate the mortar within 1 year. In normal climate condition with a humidity of 50% RH, it takes much longer to absorb water from the air and we observe a steady increase of the compressive strength over the 10-year period (see discussion above).

Among the three different redispersible powders, the styrene–acrylic copolymer LL 512 has the lowest air content of the mortars with 2.5% (Table 1) and therefore the highest compressive strength of the mortars over the 10-year period. The other two products have an air content of about 7%.

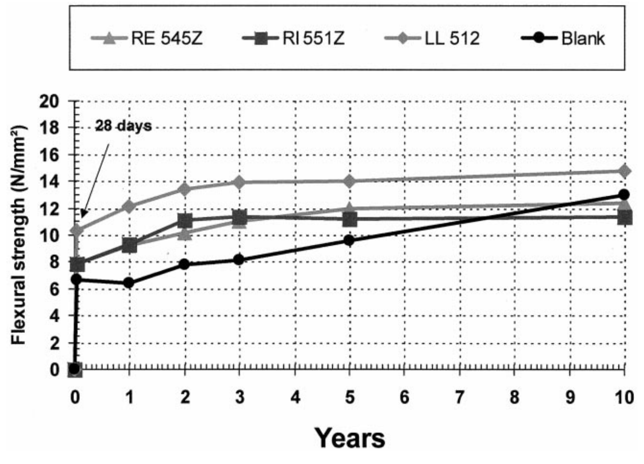

Fig. 4. Flexural strength (N/mm^2); standard deviation about 7%. Formulation 1: indoor climate conditions.

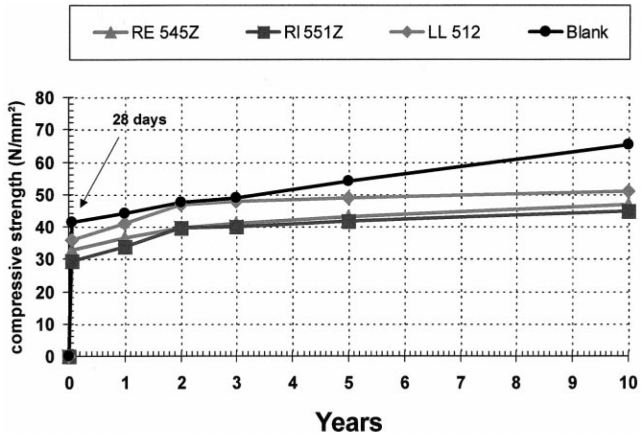

Fig. 6. Compressive strength (N/mm^2); standard deviation about 5%. Formulation 1: indoor climate conditions.

Despite this effect, all three polymers behave similarly and the mortars stay stable over the 10-year period regardless of exposure conditions.

3.4. Scanning electron microscopy

SEM is a very useful tool to show what is happening in the mortar. Isenburg and Vanderhoff [8] first used SEM to look at the structure of emulsions in mortars. We first showed, with this technique, that redispersible powders are really redispersing when a polymer-modified mortar is mixed with water and the redispersed emulsion particles of the powder are forming polymer domains in the mortar [1].

Figs. 7 and 8 show a typical distribution of a redispersible powder in the mortar, Fig. 8 shows a sample of a 10-year outdoor exposure material and Fig. 7 a 10-year indoor exposed material. We looked at numerous different samples of the three different redispersible powders; the results were always similar. These show that, in principle, a similar structure is produced with the three different polymeric materials. The redispersible powders form polymer domains in the mortar and the morphology of the polymeric materials do not change significantly over a period of 10 years.

As written in the procedures, we prepared the surface of the samples with 0.1 M nitric acid to make the domains visible. Without this preparation, it is hard to find the polymer because the crystalline material hinders direct view of the polymer material. We have used this technique already for a long time. Our experience is that by this technique we do not change the morphology of the polymeric material. We just dissolve some of the calcium hydroxide, ettringite and monosulfate, and domains of the polymers formed by film formation of the small particles of the redispersible powders become visible.

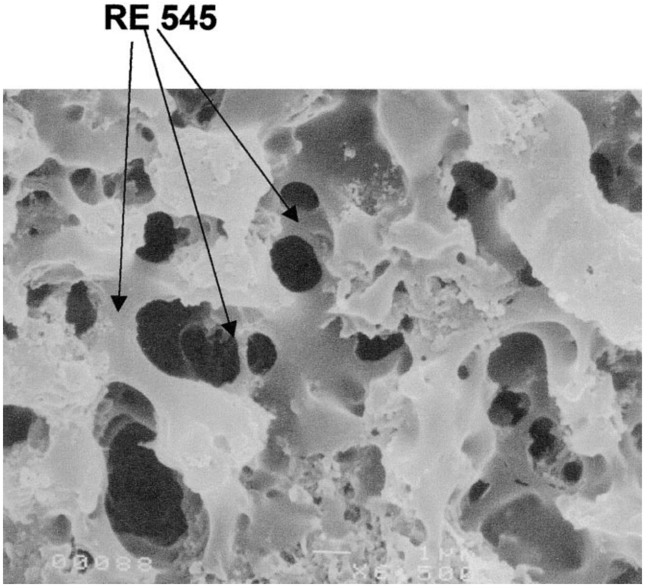

Fig. 7. Photography Formulation 1 with Vinnapas RE 545 Z 10 years NC (magnification 6500 ×).

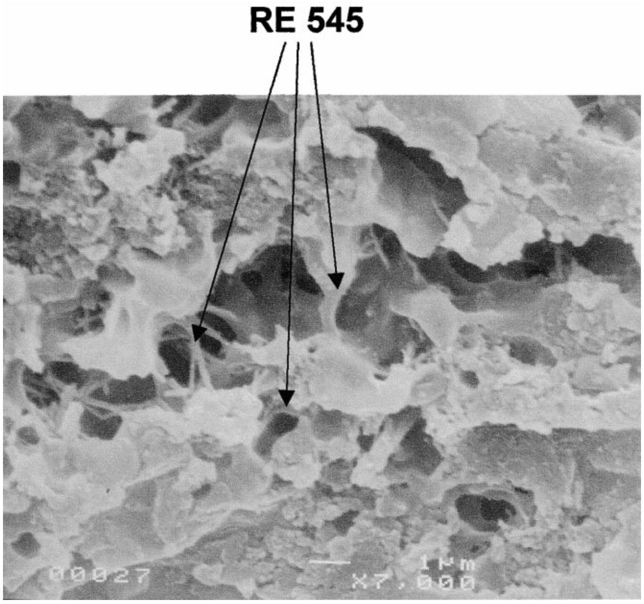

Fig. 8. Photography Formulation 1 with Vinnapas RE 545 Z 10 years outdoor (magnification 7000 ×).

3.5. Hydrophobic effect

Especially in outdoor application, as in stuccos and renderings, hydrophobic behavior of materials can be a great benefit. Water cannot penetrate into the material and, by keeping the water out of the material, no water-soluble materials diffuse into or out of the material. Structural changes caused by water in the material can be avoided by always keeping it dry. With a dry stucco or rendering, energy costs for heating houses can be

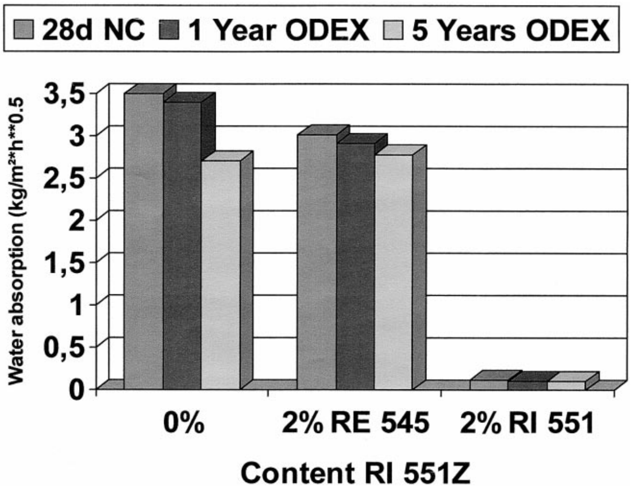

Fig. 9. Water absorption (kg/m^2* h** 0.5); standard deviation about 5%. Formulation 2: outdoor exposure.

reduced because insulation is better when no water has to be evaporated.

Besides stearates, oleates or silicone hydrophobing agents, some specialized redispersible powders can also act as a hydrophobic agent in addition to their binding properties, shown above. A typical redispersible powder as RE 545Z does not show this hydrophobic effect.

In a typical stucco formulation we compared the standard redispersible powder RE 545Z and the hydrophobic RI 551Z. Fig. 9 shows that the redispersible powder RI 551Z at a level of 2% acts as a hydrophobizing agent. The water absorption is reduced dramatically and the effect is stable over 5 years in outdoor exposure. The standard redispersible powder RE 545Z reduces the water uptake only very little compared with a sample without redispersible powder.

4. Conclusion

As well as the standard polymer for redispersible powders VAE, SA and the terpolymer based on ethylene–vinylchloride–vinyllaurate show a stable performance in outdoor and in indoor climate. The modified mortars show stable mechanical values over the 10-year period and the terpolymer also exhibits a strong hydrophobic effect.

The results of the mechanical measurements are in accordance with the SEM photographs. They show that the polymeric material stays stable for over 10 years in the cementitious surrounding. The general morphology of the polymeric material in the modified mortars is not changed. We find that the polymeric material looks the same after storage in dry NC conditions as after 10-year outdoor exposure. It is distributed as polymeric domains in the mortars acting as secondary reinforcement especially in the pores and flaws of the cementitious material. There are no signs that the redispersible powder has been redispersed a second time or has been washed out of the material.

The results of this study fit quite well into the picture of the composite material, as the polymer-modified mortars have to be seen. Both binders act in synergy. The cement, as the inorganic binder, is responsible for compressive strength, and the redispersible powder, as the organic binder, acts as reinforcement and is responsible for most of the internal tensile strength and adhesion bond strength at interfaces. [4]

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