DRY MORTAR
COORDINATION OF HIGH PERFORMANCE ADDITIVES IN DRYMIX RECIPES

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Modern dry mortars have to meet high quality standards and be economically competitive at the same time. Their production is inconceivable without the use of steadily improved additives. Basics of rheological and set-regulating additives are given for both, cementitious and gypsum systems. Conclusions from application experiences for a successful and efficient dry mortar formulation are drawn.

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1 Introduction
Today, high-performance dry-mixed systems such as self-levelling compounds and plasters can comprise up to 20 different ingredients. Drymix mortar manufacturers make considerable experimental efforts not only during the initial development of a mix design. For various reasons extensive and continuous recipe maintenance is required:

- Technical changes, e.g. of binder properties,
- Ecological aspects, esp. reduced indoor emissions, EC 1PLUS label, Blue Angel, LEED and
- Economic reasons, e.g. rising raw material costs and formulation cost optimisation.

These efforts can be significantly reduced by targeted selection of suitable dry mortar components and the knowledge of their potential interactions.

2 Premixed dry mortar basics
By definition, a drymix mortar is a homogeneous dry mixture of mineral binders, aggregates and controlling and performance-enhancing additives. The main
drymix applications are masonry mortar, grouts, thick and thin flooring screeds, renders, plasters, tile adhesives and tile grouts.

Mineral-bound mortars have been used for more than 2500 years. The industrial production of drymix mortar started in Germany after World War II. Since the 1980s, it has spread from Europe to all continents. Today, an estimated 6 to 7% of the total mortar volume is processed as prefabricated drymix mortar globally [1]. Accordingly, there is high potential for growth in the drymix mortar industry, particularly in developing countries. This trend is not only based on rising demand for more efficient building materials. It is also supported by steadily growing requirements regarding mortar properties and the development of new applications, e.g. thermal insulation function. This in turn requires high quality components, including powerful additives.

Commonly, drymix mortars are composed of binders, aggregates and additives. Typical components are:
- Cement, incl. Portland cement, Portland composite cements and special cements such as alumina cement, Portland quick cement and calcium sulphoaluminate cement
- Building lime (quicklime and slaked lime)
- Building plasters, based on alpha- and beta-calcium sulphate hemihydrate and anhydrite
- Latent hydraulic material: slag
- Pozzolanic materials, esp. trass, fly ash, clay
- Inert materials like quartz and limestone, as sands and powders
- Lightweight aggregates, i.e. based on expanded clay, shale, glass and polystyrene
- Performance additives, as described below

3 Drymix mortar performance additives

With respect to performance additives it is crucial that they are added only in small amounts while having great effects. Performance additives are used for targeted improvement of mortar properties. Their action is based on a chemical and/or physical interference. Thus plasticizers and the more powerful superplasticizers improve the flow behaviour of fresh mortar at the same water amount. Retarders and accelerators, in turn, regulate the setting and hardening of mortar.

Historically, performance additives used to be natural products. Their composition and therefore their performance, as expected, were not constant. Usually not only one target property was specifically modified but several were (often negatively) affected. Known examples of historic additives are sugar (retarder for hydraulic binders), fruit acids (retarder for gypsum), blood, starch, vinegar (air entraining agent), buttermilk, egg whites (hardening retarder & for increased tightness), lard and other animal fats and vegetable oils (as sealants).

Today’s performance additives are often produced synthetically. Based on their industrial production environment, they have a constant composition. Most common performance additive groups are:
- Rheology additives: plasticizers/superplasticizers, thickeners/stabilisers
- Retarders, accelerators/activators
- Adhesives
- Air-entraining agents, defoamers
- Shrinkage reducers
- Hydrophobizing agents
- Natural and synthetic fibres
- Pigments

In the following, two performance additive groups with high significance for drymix mortar developers are selected and will be described more in detail.

3.1 Water reducing agents

As generally known, the early plasticizer development was driven by the concrete industry. Around 1930, the first lignosulphonate-based concrete plasticizers were used. They were a by-product of cellulose manufacture. From the early 1970’s sulphonated polycondensates based on naphthalene or melamine and formaldehyde were commercialised. Even today, these technologies, especially melamine, can be found in many drymix mortar formulations. The underlying basic mechanism of liquefaction is the following: Plasticizer molecules adsorb on the solid particles (e.g. cement) whose surface is negatively charged. Identically charged surfaces repel each other. This effect is known as dispersing through electrostatic repulsion.

A quantum leap towards modern high performance superplasticizers was the invention of the so-called PCE technology around the turn of the millennium. ‘PCE’ stands for PolyCarboxylate Ether and describes a polymer which is similar to a comb in shape. The backbone consists of a polycarboxylic acid (polycarboxylate) and the side chains of the comb are made of polyether chains. Comparable to conventional plasticizers PCE molecules adsorb on solid surfaces via the polycarboxylic acid in the backbone. However, the side chains do not adsorb but extend into the aqueous solution and prevent the convergence of solid particles. This effect is known as dispersing through steric stabilisation (Fig. 1).

By varying the polymer structure, the properties of the resulting superplasticizer can be influenced to a hitherto unknown extent. The main parameters which are varied thereby are the length and nature of the polycarboxylic acid backbone and the length and number of side chains used. These essential properties can be adjusted for each application. In addition, the PCE technology allows target-oriented combination of different polymer structures, as shown i.e. in [2]. This allows adjusting essential characteristics tailored to the respective application, as
- Polymer adsorption
- Liquefaction and water reducing capacity

Additives // MATERIALS

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Key factors for the success of the PCE technology are:

- Tailor made design for specific requirements
- High water reduction
- High initial liquefaction and consistency preservation
- Strength increase
- Shrinkage reduction
- No release of formaldehyde
- No release of ammonia
- Improved cost performance

Meanwhile, PCE-based superplasticizers have been proven in almost all concrete applications as safe to use products. This is true today even for the specialty industrial floors; taking into account specific requirements for ready-mixed concrete manufacturing, installation and surface smoothening. Manufacturing conditions in a ready-mixed concrete plant are characterised by only a very limited selection of raw materials with often fluctuating raw material qualities, such as varying grading curves and moisture contents of the aggregates as well as varying cement qualities. Compared to this, there are almost ideal application conditions for high-performance additives in modern drymix mortar plants. Today's automated dosing devices can dispense a variety of raw materials with high precision, even at very low dosages [3].

The requirements for superplasticizers in drymix mortars differ substantially from those in concrete applications. This includes not only the physical state of the additive – a powder instead of a water-based solution. Additionally, there are several specific requirements regarding drymix mortars which necessitate the use of superplasticisers which are well tailored to the intended use:

- Specific dry mortar formulations, e.g. insensitivity to sulphate contents and retarders
- Mortar processing, e.g. short mixing times in silo mixing pumps, sometimes long pump lines, wobbling of screeds
- Specific requirements on the final mortar product.

According to experience, not just one liquefier meets all different application requirement profiles but various tailored polymers and combinations of them have been developed, instead.

### 3.2 Set-controlling additives

The setting and hardening of the binder can be precisely controlled by the use of additives.

Accelerators are distinguished in setting and hardening accelerators. In case of setting accelerators, the additive intervenes in the setting process beginning in the fresh mortar state when the matrix is still plastic. Typically, the chemical reaction of the hydraulic binder is shifted to earlier times. Consequently, the workability time is reduced. In general, the early strength can be increased by these agents, but at the cost of declining final strength of the mortar.

Special requirements are imposed on setting accelerators in the application of sprayed cementitious mortar and concrete. They are required i.e. in tunnel works in order to enable greater layer thicknesses which can withstand higher stresses. Typically, these accelerators are based on sodium silicates (which reduce setting time dramatically to 5...10 min but also reduce the strength at later ages) or on aluminium sulphate in the case of the alkali free accelerators (slightly less effective but also less strength losses).

Alkali silicates are available in powder form, too. Alternatively to silicate-based accelerators, targeted ettringite formation (3 CaO·Al₂O₃·3 CaSO₄·32 H₂O) is achieved in dry mixes by adding high alumina cement (HAC, also known as ‘calcium aluminate cements’) and calcium sulpho aluminate cement or alumina in powder form. Mortars based on high alumina cements can even be further accelerated by using lithium carbonate, lithium sulphate and lithium hydroxide as set accelerator.

Hardening accelerators, on the other hand, are used when the so-called early strength (in the first hours to a few days) of cementitious systems have to be increased. In the past, chloride salts were widely used. The more recent chloride-free hardening accelerators are based on calcium nitrate, nitrite, thiocyanate, thiosulphate or formiate and ethanol-amines.

Also for gypsum-based systems, a range of setting accelerator techniques exists. Most effective setting accelerator for Plaster of Paris, which mainly consists of beta calcium sulphate hemihydrate, is fine ground gypsum, also called BMA (Ball Mill Accelerator). In this case, mechanically activated gypsum nanoparticles act as seeds to initiate the crystal growth. A known drawback of these products is their loss of effectiveness during storage due to aging [4].
Plaster of Paris is characterized by both a high solubility and a high solution rate. Thus a further increase of calcium and/or sulphate ion concentration in the solution is not as crucial for hydration speed as the previously described seeding. In anhydrite and alpha hemihydrate systems, on the other hand, the addition of an alkali sulphate, typically K₂SO₄, as sulphate component and calcium carriers like CaO, Ca(OH)₂ or cement can significantly accelerate the hydration. In the case of anhydrite these components are even crucial to activate the binder reaction (so-called sulphatic and/or alkaline activation). Cement, especially when added in larger amounts, not only activates the gypsum binder reaction itself but also contributes to strength development due its own hydration.

At this point it needs to be mentioned, that superplasticizer can also be used for the increase of both early and final strength. The effect is based on significant reduction of the mixing water dosage and therefore the water to binder ratio.

In contrast, retarders are used to increase the setting time. In Portland cement systems, retarders act in particular on the calcium aluminate hydration which is dominant in the first minutes to hours. Typical cement retarders are based on citric acid, carboxylic acid, gluconate, glucose as well as zinc salts.

Effective gypsum retarders interfere with the nucleation and/or gypsum crystal growth. The general mechanism of retardation is based on adsorption on the gypsum crystal surfaces, thus interfering with the further crystal growth. The further integration of calcium and sulphate ions can be blocked completely or partially. Fruit acids and their salts, especially citric acid and citrates as well as tartaric acid and tartrates, are commonly used retarders in calcium sulphate-based drymix mortar formulations. A typical side effect of citric acid is strength loss caused by changes in gypsum crystal morphology. Tartaric acid, instead, leads to an extension of final setting which is only useful during plastering works. Alternative technologies are based on phosphates and phosphonates, protein hydrolysates and amino acids.

In numerous gypsum-based dry mixes a combination of both, accelerator and retarder, is used. This may seem paradoxical at a first glance. Especially, anhydrite systems need acceleration to initiate setting and hardening and to shift it to an earlier time. The additional use of the retarder then becomes necessary in order to adjust the needed workability time.

The retarder addition can even have a positive rheological influence: Acceleration can be accompanied by a reduced flow of the binder slurry. The addition of retarder counterbalances this negative effect, as exemplary shown in Example 3. Another example of successful application of the combination of accelerator and retarder is the appearance of the so-called ‘snap set’ during modern gypsum board production [5].

4 Application experiences with performance additives
Drymix mortars, such as self-levelling underlayments and screeds are nowadays successfully formulated with PCE based superplasticizers. Drymix mortar developers especially appreciate the high water reducing power of PCEs, which is the basis for strength increase, shrinkage reduction and formulation costs optimisation. Also appreciated is, last but not least, the possibility to selectively adjust the fresh mortar consistency to the application needs.

It can be shown by the following examples, that a basic understanding of the interactions in drymix systems is necessary to efficiently and successfully develop drymix mortar formulations with high-performance additives.

4.1 Example 1: Ternary self-levelling underlayment (SLU)
The drymix formulation of a self-levelling compound based on three binder components (calcium, alumina and sulphate carrier) needed to be optimised. In the

![Image](2a)

2a Influence of superplasticizer dosage on the slump flow (retarder constant 0.20 %)

![Image](2b)

2b Influence of retarder dosage on the slump flow (superplasticizer constant 0.06 %)

250 300 350 400 450 500 600 750 250 300 350 400 450 500 600 750 0 15 30 45 60 75 0 15 30 45 60 75 a) b)
course of this, the effect of various additives on the slump flow (using the Haegermann funnel) was determined (Fig. 2a and 2b).

As expected, the test results confirmed the high liquefaction potential of the selected PCE-based superplasticizer (here: Sika ViscoCrete-225 P). Moreover, it has been found that in addition to the actual rheology additives, especially set-regulating additives (here: retarder tartaric acid) can significantly affect the flow behaviour of mortar. This causes problems, if the setting starts before the fresh mortar processing. In the above example, the combination of 0.06 % superplasticizer and 0.20 % retarder fulfilled the product requirements regarding both flowability and workability (Fig. 3b).

4.2 Example 2: Calcium sulphate-based self-levelling screed
The reference formulation with calcium sulphate binder and melamine-based plasticizer needed to be re-designed due to various aspects:

» Demand for higher water reduction, because the existing screed showed weak strength due to high water demand of drymix mortar components
» Development of a healthy and environmentally friendly formula that will meet future stringent regulations (e.g. regarding formaldehyde)
» Reduction of formulation costs

Initially the required fresh mortar properties were set by selecting the appropriate superplasticizer (here: Sika ViscoCrete-225 P) and retarder (here: Sika Retardan-200 P) and adaptation of the defoamer dosage. By exchanging of melamine by PCE and 10 % additional water reduction the desired initial liquefaction and open time were achieved. The efficiency ratio of melamine to PCE was about 1:8, whereby the cost of the total formulation could be significantly reduced. As expected, the water reduction resulted in strength increase which in this case was about 18 %. During large-scale application, the developed formulation also proved to be particularly insensitive to temperature fluctuations (Fig. 3a).

4.3 Example 3: Plaster (beta calcium sulphate hemihydrate)
The effect of different gypsum retarders has been tested in plasters based on natural and flue gas desulphurisation (FGD) gypsum. When comparing retarding efficiency (in this case additive dosage to reach 40 min. workability time), only about 30 % of Sika Retardan-200 L is required versus protein hydrolysate, and less than 20 % versus dosage of amino acid A [5]. The retarder addition not only influences the setting time, but it can also have a positive rheological effect, as shown in Table 1.

All tested gypsum retarders significantly improved the flow behaviour of accelerated plaster with both natural and FGD-gypsum. Under the chosen conditions, retarder dosage variations did not influence the slump flow. As generally known, water is chemically bound during hydration and new crystals are formed, thus, increasing the need for water (to reach the same flow). It is obvious, that the retarder prevents the hydration and the formation of additional surface due to crystal-
lisation. Thus the tested retarders exhibited a positive side effect: They indirectly act as a water reducer. By the adjustment of the retarder dosage a drymix formulation can be designed where the crystal growth and thereby flow loss would not start within but right after the desired processing time.

5 Conclusions for successful and efficient drymix mortar formulation

Increasing technical requirements on mortar properties and the demand for more efficient building materials requires the use of powerful performance additives. For drymix mortar developers it is increasingly necessary to have an overview of the available technologies and to know their entire product performance. Superplasticizers based on PCE-technology, for example, can be perfectly tailored to the intended purposes. During drymix mortar formulation development and/or adjustment, first targeted selection of the appropriate additives according to their intended purpose is crucial. Beyond that, all relevant mortar processing requirements as well as excellent and damage-free final product properties have to be taken into consideration. If necessary, the dosage of other relevant drymix components (typically plasticizer, accelerator, retarder, defoamer and stabiliser) has to be adapted. Practice shows, that the communication between additive supplier, drymix mortar manufacturer and processor is crucial for a fast and efficient product solution.

REFERENCES

GLOBAL BUT LOCAL PARTNERSHIP

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Sika AG, Switzerland, is a globally active specialty chemicals company. Sika supplies the building and construction industry as well as manufacturing industries (automotive, bus, truck, rail, solar and wind power plants, façades). Sika is a leader in processing materials used in sealing, bonding, damping, reinforcing and protecting loadbearing structures. Sika’s product lines feature high quality concrete admixtures, specialty mortars, sealants and adhesives, damping and reinforcing materials, structural strengthening systems, industrial flooring as well as roofing and waterproofing systems.

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