Advanced Dry Mortar Technology for Construction Industry

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Abstract

Products developed based on advanced dry mortar technology have widely been used for various applications in the construction industry in European countries. Most of the dry mix products can provide outstanding properties to meet nowadays stringent performance requirements. If used properly, they can be very cost effective building materials to minimize some potential construction problems and to ensure the long-term integrity of the structures. However, the usage and popularity of dry mix products is still lagging behind in Hong Kong. It is urged that the property owners or designers should study their benefits and consider specifying the dry mix for their new developments and renovation works so as to improve the quality of the structures by simple materials approach.

1.0 Introduction

Lime-based and gypsum-based mortars have been used for thousands of years in the erection of building structures. In the past, these simple paste substance known as mortars have mainly been used as bedding materials for laying stones and bricks as well as rendering materials for wall plaster applications.

Similar applications of these basic mortars have continuously been used and adopted in the construction for nearly all building structures. However, since 1950s the mineral binder within the mortar is gradually changed from lime and gypsum to cement as a result of the easy availability of Portland cement. From that time onwards, the so-called job-site mortar technology has been introduced and applied in the construction industry worldwide. The main ingredients of the job-site mortars are mainly cement and sand which are transported separately to the job sites and mixed together by hand in the appropriate ratio with the addition of water to produce wet mortars for simple applications.

During the 1960s in Western Europe, there was a fast-growing demand in the
construction industry for speedy erection of new buildings with better quality of construction. In order to improve the properties and performance of the job-site mortars, small quantity of liquid dispersion and plasticizer was also added to the mix. However, due to a shortage of skillful workers and an increase in complexity of material applications, job-site mortar technology was not able to adequately meet the demand on achieving specific performance and consistent quality requirements.

Consequently, with the development and availability of new chemical additives in powdery form, the dry-mix mortar technology was invented in Western Europe to overcome the deficiency of the job-site mixed mortars with liquid dispersions. The introduction of associated production facilities and machine application techniques in Germany also accelerated the replacement of job-site mortars by highly efficient factory premixed dry-mix mortars. These pre-bagged dry mortar products can enable a significant increase on construction productivity as well as a substantial enhancement on building quality based on simple mix and apply operations. As a result, their adaptations and applications are spread quickly to other modern countries around the world.

Nowadays, with the continuous advancement in dry-mix mortar technology over the years, some advanced dry mortar products have been developed and introduced to the construction industry. These products can improve the durability of the structures and provide simple solutions for some construction problems. The applications of these advanced dry-mix mortars and their associated systems are quite versatile and in general very cost effective.

### 2.0 Job-Site Mortar Technology

For a particular job-site mixed mortar, a specific ratio of cement and sand is batched and mixed before adding the mixing water and sometimes with liquid admixtures. The quality of the site-mixed mortar depends on the quality of the raw materials, their correct batching ratio, the homogeneity of the mixture, and the consistency of the fresh mortar. Under these batch and mix conditions, the quality of the site-mixed mortars cannot easily be guaranteed. The major disadvantages of site-mixed mortars are that the whole manufacturing process cannot be controlled easily, and the workers who make up the mortars cannot ensure the quality due to possible errors during various
steps in preparing the mortars. Besides, the liquid additives can either not being added or only be added with a high risk of incorrect dosage and mixing errors ending up with significant variations from batch to batch. With the above constraints and potential inconsistency, mortars based on job-site mix technology are unable to provide highly specialized properties of consistent performance. Therefore, the applications of the job-site mixed mortars nowadays are limited to those un-important low performance areas and non-structural work without a concern on quality or durability.

3.0 Dry-Mix Mortar Technology

In contrast to job-site mortars, the modern dry-mix mortars are produced in a special factory with dedicated facilities on batching and blending of all the necessary ingredients in highly-controlled process. In this way, different types of dry-mix mortar products with well-defined properties and performance to meet specific requirements and applications can be produced. The use of premixed dry mortars not only increases significantly product performance but also guarantees a high degree of application reliability and consistency. Factory premixed dry mortars ensure binders, fillers and chemical additives of known quality are blended exactly in the same ratio thus ensuring high degree of product performance and consistency.

4.0 Raw Materials for Dry-Mix Mortar

Most of the dry-mix mortar products require only the addition of potable water and mixed with a simple mixer to produce high quality fresh mortars. Although the dry mortars are relatively easy to prepare and use, the ingredients and their proportions of each products are sometimes very complicated. Most of the high performance products are usually based on extensive development process and tests in order to achieve the designed materials properties. In contrast to job-site mortar of simple ingredients and proportions, the types of raw materials used for production of dry-mix mortars are numerous and their mix proportions are complicated. The raw materials used for dry-mix can generally be grouped into four main categories (binders, fillers, chemical additives, pigments) and some of the basic generic types are listed below:

(1) Binders
- Ordinary Portland cement (OPC)
- High alumina cement (HAC)
- Ground granulated blast furnace slag (GGBFS)
- Pulverized fuel ash (PFA)
- Micro silica
- Hydrated lime
- Gypsum
- Anhydrite
- Polymer

(2) Fillers
- Silica sand
- Quartz sand
- Limestone powder
- Silica powder
- Bentonite
- Perlite
- Polystyrene
- Vermiculite
- Expansion clay
- Cellulose fibre
- Polypropylene fibre

(3) Chemical Additives
- Cellulose esters
- Superplasticizers
- Thickening agents
- Air entraining agents
- Accelerating agents
- Retarding agents
- Defoaming agents
- Hydrophobic agents
- Plasticizing agents
- Shrinkage compensation agents

(4) Pigments
- Inorganic pigments
- Organic pigments
Most of the dry-mix mortar products contain both mineral cementitious binder (e.g. OPC) and polymer binder (e.g. re-dispersible powder) and they are normally packed in bags after mixing in the factory. Hence, the dry-mix mortar products are also known as Pre-mixed or Pre-bagged Polymer Modified Cementitious Mortar.

5.0 Production of Dry-Mix Mortar

Well established dry-mix mortar production plant (Figure 1) is normally equipped with computer controlled batching, dosing and mixing facilities. For some sizable plants, they also have their own sand drying and grading facilities to handling the production of graded sands to be stored in silo containers. Depending on the setting up and associated facilities of the plant, the annual output production capacity can range from 20,000 Ton to 200,000 Ton.

For advanced dry mortar manufacturing plants with modern facilities, the production sequences are almost fully automatic with all the devices controlled
and monitored by electronic sensors. The automatic dosing system (Figure 2) is usually very precise with extremely high accuracy (e.g. 30kg ± 3g, 0.01%) especially for batching high performance chemical additives. The batching sequences and mixing cycles are specially designed for each product to ensure the powdery ingredients are blended to form a homogeneous mixture within the batch. For a highly efficient modern plant, the mixing time for each batch (say 2 Tons) may be as short as 2 to 5 minutes depending on type and complexity of the product.

![Figure 2 – Schematic Diagram Showing Automatic Dosing and Mixing System](image)

Since the production is automatic and closely monitored by electronic devices, the product consistency is expected to be high provided that a tight quality control on the raw materials and products is performed. Therefore, for a top or world class dry mortar plant, a comprehensive and stringent quality control systems on both raw materials and finished products are implemented. Besides, a team of research specialist and technical staff is required to be stationed at the plant to provide continuous development and monitoring on products and production controls to guarantee the product performance.
6.0 Type of Dry Mortar Products

In general, dry mortar products based on advanced dry-mix technology can be classified into 2 main types (basic grade and technical grade) according to their compositions and applications.

<table>
<thead>
<tr>
<th>Type of Dry Mortar :</th>
<th>Basic Grade</th>
<th>Technical Grade</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compositions :</td>
<td>Simple</td>
<td>Complicate</td>
</tr>
<tr>
<td>Typical Products :</td>
<td>Masonry mortar, Wall render, Base plaster, Skimcoat, Floor screed</td>
<td>Thixotropic mortar, Decorative plaster, Tile adhesive, Tile grout, Waterproofing, Non shrink grout, Repair mortar, Self leveling floor, Thermal insulation, Sound insulation</td>
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The basic dry mortar products are manufactured to replace the traditional job-site mixed mortars with improved quality and enhanced consistency. While the technical dry mortars are advanced products developed to meet latest building requirements and usually with distinct high performance properties which cannot be easily produced and achieved with job-site mixed mortars.

7.0 Failure of External Finishes of Buildings

In the last decade, the problems of external and internal finishes failure in forms of delaminated renders and debonded tiles have been reported from many old buildings as well as some newly constructed buildings in Hong Kong. Some of the likely causes of the failure in buildings and the possible improvements with the use of advanced dry mortar building materials are briefly discussed below:

The most common external and internal wall finish system (Figure 3) for buildings in Hong Kong consists of the following elements:

(1) Concrete substrate with spatterdash
(2) Wall render  
(3) Tile adhesive  
(4) Ceramic tile  
(5) Tile grout

There are four possible failure modes of the wall finishes:
(1) Wall render (render delaminated from the concrete substrate)  
(2) Tile adhesive (adhesive debonded from the wall render)  
(3) Ceramic tile (tile detached from the tile adhesive)  
(4) Tile grout (grout material is cracked and fallen out of the tile joints)

7.1 Wall Render Failure

In Hong Kong, the use of site-mixed mortars for applications of wall render nearly becomes obsolete except in small building projects at remote sites. Most of the rendering mortars are supplied in form of ready-mixed mortar produced from a concrete batching plant for bulk delivery to the job site using a concrete truck. It is quite common and understandable to order a full truck load of 6 or 7m³ wet mortar so as to save the delivery cost and simplify the logistic arrangement. It has been known that a significant amount of plasticizer with strong retardation strength is added by the producers to extend
the working life of the mortars. The normal industrial practice has been set for 24 to 36 hours retardation thus pushing the usable life of the rendering mortars to an extreme limit. Besides, certain amount of air-entraining agent is dosed and sometimes PFA is added to reduce the weight of the mortar as well as enhancing the workability.

With very strong retardation, the wet mortar does not hydrate and start initial setting until the retarding effect has expired. In some worst cases, the cement in the mortar applied onto the wall can remain in un-hydrated form after a day or so. However, the free water within the applied mortar may be reduced significantly due to suction by the substrate and evaporation to the ambient. Thus, the water loss makes the mortar stiffened but in fact no real strength (compressive and bond) generated from cement hydration even it is already on the wall for sometimes. Without proper curing, the render surface is relatively soft during the first few days and becomes dusty if PFA is also included in the mortar. Due to a lack of water for delayed cement hydration, the adhesion or bonding strength between the substrate and the wall render is expected to be relatively weak. If any early age external vibration or movement is imposed to these weak renders via surrounding building activities, the possible slight premature delamination or further damage of the weak bond may be resulted. From some random in-situ direct pull-off test results on render of ready mixed mortar, the bonding strengths are quite low and typical values of 0.1 to 0.2MPa are commonly found.

With the fact that some shrinkage cracks may have generated within the render, weak render at localized area tends to delaminate and pop out when subject to slight shear movement (thermal or shrinkage or structural) across the bonding interface during its service life. Hence, occasional incidence of falling and delaminated render at external façade (Figure 4) and internal walls from new or old high rise buildings is reported. The reason of failure may be associated with weak bonding of the cracked render layer to substrate due to inherent mortar performance and/or sub-standard workmanship. Other possible factors may be structural shortening of the buildings under creep, structural movement, lack of joints within render, differentiate thermal expansion / contraction of substrate and finishes, and poor quality spatter dash, etc.
Having understood the likely deficiency of the commonly adopted ready mixed mortar and the associated potential risks on failure, a better render material may be required so as to minimize or overcome some of the problems. A feasible improved approach is to use proprietary dry premixed base plaster, which can be applied with machine spraying, as wall rendering mortar of superior performance.

A good quality dry-mix render usually includes the following special chemical additives in appropriate proportions to enhance specific physical properties during fresh and hardened stage:

1. Cellulose ether - water retention to minimize suction and water loss so as to enhance better hydration of cement, improve bonding and reduce shrinkage cracks
2. Starch ether – improve workability and sag resistance for better build-up
3. Hydrated lime – set control and enhance workability
4. Polymer binder – addition adhesive strength to smooth substrate and increase flexibility to reduce shear stress induced by movements
5. Hydrophobic agent (Optional) – extra water resistance properties
From the above, with the inclusion of special additives in the dry-mix render material, it can provide and enhance necessary functions for a rendering material during applications in particular workability and ease of build up. Besides, extra benefits such as water retention, set control, reduce cracks, improve bond and better elasticity/flexibility are also included to ensure long-term durability and performance during the services life. Not only consistent finish quality can be achieved but also the productivity rate can be increased with the use of machine spraying application technique. More important, it reduces the potential problems from workers during handling and applications.

For some applications, liquid emulsion such as SBR dispersion is added to the ready mixed mortar to provide waterproofing properties or hopefully to improve bonding performance for external render. However, due to the delayed application of ready mixed mortar, some isolated SBR films are already formed before the mortar is applied onto the wall ending up with an undesirable debonding zone affecting the adhesion performance. The addition of the SBR dispersion is very difficult to control, therefore, the performance of the mixed mortar is always questionable. With the use of dry-mix waterproofing mortar for rendering, both the bonding strength and waterproofing properties can be guaranteed. Based on the above technical information and comparisons, the dry-mix plaster can surely out-perform traditional ready mixed mortar in terms of performance and long-term durability. Therefore, dry-mix plaster should be the preferred materials and adopted for new rendering work to achieve better performance and quality.

However, it is important to note that not all the dry mix render products commercially available are identical and some of them may not able to provide all the desirable properties for the intended applications. In particular for simple low grade dry mix render products some of the important ingredients such as polymer binders (i.e. re-dispersible powders) are missing. These simple grade render products are mainly developed for low rise brick wall (or masonry) applications in Europe and they may not be suitable for high rise smooth and dense concrete wall applications in Hong Kong. Without the inclusion of the polymer binders, both flexibility and the adhesion strength of the render are reduced in particular onto concrete wall surface cast with smooth formwork. Besides, some imported products from overseas countries may not suitable due to difference in climatic conditions and application
practice. Hence, it may be useful to discuss with a dry mortar specialist or professional materials engineers on selection of appropriate products or systems. With the use of advanced dry mortar technology, a leading dry mortar expert can able to formulate precisely and develop high performance dry mix materials with sufficient flexibility and adequate bonding strength to fulfill the stringent requirements for use as a durable high-rise external finishes.

Nevertheless, if ready mixed mortar is still being used in the current projects or to be adopted in coming developments, awareness on the potential problems should be taken and precautions on critical areas should be considered in order to avoid or minimize future failure.

7.2 Tile Adhesive and Tile Failure

In some cases, tile adhesive is debonded from the render layer (Figure 5 and 6) due to poor bonding to the render surface. The reasons may be the outer render surface to receive tile adhesive is relatively weak as a result of poor cured ready mixed rendering mortar. Besides, it may also be related to the inferior quality tile adhesive being prepared and used on site.
In Hong Kong, there are still specifications allowing the use of site-mixed mortars with addition of liquid polymer dispersion as adhesive mortars for sticking tiles. Theoretically, with the inclusion of good quality and sufficient quantity of liquid polymer dispersion, the adhesion of the well mixed and prepared mortar should be of acceptable performance for ceramic tiles. However, it has been known that with the addition of the liquid dispersion, the workability may be poor and the open time for tiling is relatively short. Hence, there is a tendency for tile applicators to use less liquid dispersion in order to have better workability as well as save cost for the dispersion and simplify the mixing effort. There were some cases that the actual quantity of liquid dispersion consumed on the projects was only a fraction of the expected consumption indicating it was added much lower than the designed dosage. It is possible that the liquid dispersion may have been diluted with reduced solid contents that affecting the associated bond performance. With the relatively short open time of the adhesive, there is a high risk of improper adhesion bonding to the tiles. Hence, in order to avoid the inconsistency adhesive quality due to intentional or un-intentional mal-practice, the use of
site mixed products with liquid emulsion should be avoided and they should be replaced by proprietary dry mix adhesive.

At present, the use of pre-bagged tile adhesive is becoming more common due to its more easier in handling and improved performance. However, most of the specifications have not specified clearly the requirements of the tile adhesive in relation to the tile types and sizes, locations or areas of tile applications. In Hong Kong, until now, it is quite normal to specify for a basic pre-bagged tile adhesive to meet the obsolete BS5980 : 1980 requirements for all the tiling applications. Traditional tile adhesive to BS5980 may work for normal small size ceramic wall and floor tile for internal use. It may be not suitable for high quality non-porous tiles such as full-vitrified, porcelain or glass tiles especially for external wall applications at high rise buildings. Nowadays, more and more of these high quality non-porous tiles have been selected for installation by the Architects due to better resistance to weathering and less dirt pick-up. But the fact on the need to use special or appropriate adhesive to stick them properly is always overlooked and usually not considered during actual installation or included in specification clauses. Hence, the incompatibility of tile and tile adhesive do exist and sometimes can result in premature failure of bonding even at newly constructed buildings.

High quality non-porous tiles are known to be relatively difficult to bond due to low surface porosity and low water absorption properties. A high class polymer modified adhesive of improved quality must be used to ensure the long term bonding adhesion between the tiles and the substrate. If these tiles are installed at high level locations of a building then an adhesive with enhanced additional flexibility is required to accommodate likely movements. Better performance specifications from EN12004 are available for the improved tile adhesives (e.g. Class C2TE). It is recommended to adopt these latest standards for installation of tiles for new high rise building projects. It is relatively important to select appropriate and correct class of adhesive to install the selected tiles especially with those non-porous high performance tiles. The architects may aware the tile quality has been improved but they do not realize the associated need of special adhesive for these tiles. It is true to point out that the adhesive systems work in the past with normal ceramic tiles (water absorption < 3%) may not work anymore (or durable enough) with the high performance non-porous tiles (water absorption < 0.2%).
With the advanced dry mix technology, different tile adhesives are available to provide various critical performance properties such as high tensile adhesion strength, long open time, good sag resistance, fast set and enhanced flexibility, etc for most difficult applications on various substrates and tile types.

7.3 Tile Grout Failure

In the past, tile grouts are thought to be used as a material to fill the joints between tiles for aesthetic purposes only. Therefore, inferior materials such as white cement or simple coloured cement material are used to fill the tile joints. Hence, sometimes the grout material cracks with white coloured substance leaching out as efflorescence (Figure 7). Besides, rain water may seepage and penetrate through the porous structures or cracks within the tile grout. The trapped water behind the tile will slightly expand under heating and create stress to weaken the bonding of the tile to the substrate repeatedly resulting in localized failure.

![Figure 7 – Efflorescence of Tile Grout](image)

The tile grout, in fact, is a fairly important material to reduce the stress within
the whole tiling wall upon thermal movement of the tiles and structural movement of the structure. It must also have the ability to prevent the water from penetrating into the back side of the tile to create harmful stress and weaken the tile bond. With the advanced dry mix technology, tile grout of superior performance properties such as waterproofing, flexibility, low shrinkage, good abrasion resistance, resistance to mould growth, stable colour and resistance to efflorescence, etc. is available. The use of high performance dry mix tile grout would help and enhance the overall integrity of the external tile finishes at buildings. Although, the cost of the tile grout and consumption quantity within a project is insignificant, correct choice of good quality one will surely add benefit to the overall durability and appearance of the building façade.

8.0 Improved Performance Wall Finishes System

It is important to point out that the failure of internal and external wall finishes (i.e. render, tile adhesive, tile and grout) are complicated issues. The causes of failure of wall finishes may be related to one or several combinations of the possible factors or modes depending on the actual conditions for a particular building. Nowadays, many people within the construction industry still think the wall finishes especially wall render and tiling operations are simple and non-structural works within building projects. Therefore, the importance and details are always overlooked during the design and construction stages. They only realize the critical impact on overall integrity once delamination or failure occurs later resulting in serious damage or major repair.

The author only wants to highlight some of the potential problems encountered with external and internal wall finishes based on traditional approach or materials. Besides, a wall finish system with improved performance is suggested with the use of polymer modified dry mix mortars to minimize the failure risks due to problematic materials, questionable workmanship or parameters that overlooked during design, etc.

The following is a suggested wall finish system with improved properties and performance:
(1) Use proprietary key-coat to replace site-mixed spatter-dash
(2) Use premixed polymer modified base plaster to replace ready mixed mortar
(3) Use high class premixed flexible tile adhesive to replace traditional
standard grade tile adhesive

(4) Use low shrinkage waterproof tile grout to replace traditional tile joint filler

Through the use of the above high quality dry mix system, the integrity of the wall finishes will surely be significantly enhanced with better bonding adhesion strength for each interfacial layer and more flexibility to reduce induced shear stress from various movements. The building will be more durable and the potential savings on long term maintenance expenses will be substantial.

9.0 Comments

Based on the above brief discussion, good quality dry mix products are available in the market with improved performance. Although, dry mortars cannot totally solve all the construction problems, they can at least provide a proper or more advanced materials approach to minimum the potential failure and enhance the durability of structures. In fact, pre-bagged dry mix is no longer of simple ingredients packed in paper bag based on cement, dry sand and minor plasticizers. On the contrary, advanced dry mortars are very complicated powdery mixtures with sophisticated chemical additives of latest technology to provide wide range of superior performance to meet complex construction requirements.

There are plenty of the dry mortar products available in the market to substitute and improve the traditional materials such as leakage problems of sheet waterproofing membranes replace by cementitious waterproofing slurries, thick brittle epoxy floor replace by self leveling floor system, etc. Besides, many innovative applications and environmentally friendly products have been developed based on the advanced dry mortar technology with latest chemical additives.

Advanced dry mortar products have been used with proven records in Europe and Western developed countries for a long time and the trend is still growing. Mainland China government has imposed regulations to encourage and promote the use of dry mortars in major cities such as Beijing and Shanghai to minimize the construction problems and improve the building quality. Besides, several professional official bodies have been set up to develop new specifications and standards to provide directions and guidelines for the construction industry to adopt latest dry mortar products and technology.
Some of them are developed in line with the latest European and ISO standards.

However, the usage of dry mortar products in Hong Kong is comparative lagging behind. In fact, the rate of implementation and usage of these advanced construction products in China is much wide-spread and quicker than those in Hong Kong. Most of building materials specifiers such as architects or government engineers in Hong Kong do not aware the availability of these new advanced products or some do not know how to make use of them. Hence, it is urged that a study group should be setup within the industry so as to provide some guidelines of dry mix products for use in Hong Kong to improve the present construction quality. Besides, the property owners or designers should start to study the outstanding benefits of the dry mix and consider specifying them for their development and renovation works to improve the quality of the structures in a simple and straight-forward approach.

References

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