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Concrete Repair under Dynamic Loads with Polymer Modified Mortars

Réparation du béton, sous charge dynamique, à l'aide de ciments et de résine époxyde

Betonreparatur unter dynamischen Lasten mit Polymer-modifiziertem Mörtel

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SUMMARY

Since the first generation of repair products using epoxy and cement technology, extensive research has been done to improve such systems in order to make them meet the highest performance requirements. These new generation of epoxy-cement products is ideally suited for extensive rehabilitation work on bridges heavily damaged by frost and deicing salts. Vibration caused by dynamic loads may have an influence on the bond and on the crack-free hardening of the repair material. Extensive testing in laboratories on samples applied under static and dynamic loads allow to optimize repair compounds so that their performance is unimpaired by dynamic loads during application.

RÉSUMÉ

Des travaux de recherche extensifs ont permis d'éliminer les désavantages des mortiers de réparation à base de ciment et de résine de la première génération. Les systèmes de la seconde génération sont parfaitement adaptés aux travaux de restauration de haute qualité, tels que ponts gravement détériorés par le gel et les sels de déverglaçage. Les vibrations, provoquées par le trafic pendant les travaux, peuvent avoir des conséquences néfastes sur l'adhérence et le durcissement des matériaux de réparation. Des essais extensifs en laboratoire sur le comportement des mortiers sous des charges statiques et dynamiques, permettent d'optimaliser les formulations des produits de réparation de façon à pouvoir garantir que leur performance ne subit pas l'influence des effets dynamiques provoqués par le trafic pendant les travaux.

ZUSAMMENFASSUNG

ECC-Mörtel vereinigen die positiven chemischen und mechanischen Eigenschaften von Epoxidharzen mit den guten physikalischen Eigenschaften von Zement. Mehrjährige intensive Forschungsarbeit war notwendig, um die baupraktischen Nachteile epoxidharzvergüteter Zementmörtel der ersten Generation zu eliminieren und die hohen Anforderungen, welche an ein grossflächiges Brückensanierungssystem gestellt werden, zu erfüllen. Durch die Nutzung von Brücken während der Instandsetzung entstehen Schwingungen, welche den Haftverbund und das rissfreie Aushärten eines Reparaturmörtels nachteilig beeinflussen können. Umfangreiche Versuche von statisch und dynamisch belasteten Verbundkörpern ermöglichen die Optimierung von Sanierungssystemen, welche eine einwandfreie Betoninstandsetzung unter Betrieb garantieren müssen.

1. RESTORATION OF REINFORCED CONCRETE BRIDGES

An enormous amount of construction work has been done in short time during the boom period of the Sixties and Seventies in Europe. Fundamental rules of construction practice, such as protecting the bridges against penetration of aggressive detrimental substances, have been disregarded. The still little known effects of de-icing salts, of increasing acidity of rainwater and of mounting aggressivity of air pollution, have been underestimated. The concrete of the bridge decks under the wear course, the shoulders and piers in the splash zone, above all show considerable corrosion damages. The repair mortars used for the restoration of reinforced concrete bridges have evolved rapidly during the last 20 years.[1]

2. REQUIREMENTS FOR CONCRETE RESTORATION WORK

The aim of concrete repair is not only to restore the original condition but also to give durable protection against further deterioration. The aggravating damages call for always better quality materials and have led to the following demanding qualification criteria for repair mortars:

- **Structural bond between concrete substrate and repair mortar.**
  - ⇒ high bond strength
  - ⇒ good water retention
- **No spallation caused by strain differentials from different thermal dilatations, shrinkage or swelling.**
  - ⇒ same thermal dilatation characteristics as the substrate
  - ⇒ low chemical and physical shrinkage
- **No overstress caused by differing material-characteristics of concrete and repair mortar.**
  - ⇒ matching E-moduli (also at low temperatures)
  - ⇒ adequate compressive strength
- **Effective protection against detrimental environmental attack(liquid/gaseous).**
  - ⇒ high degree of impermeability (CO_2 / H_2O)
  - ⇒ low w/c ratio
  - ⇒ resistance against freeze-thaw cycles and de-icing salt
  - ⇒ crack-free hardening
- **Suitable for site conditions, i.e. easy and efficient application.**
  - ⇒ long pot life and opentime
  - ⇒ non-sag
  - ⇒ suitable for machine application
- **Satisfactory esthetics of the structure after restoration.**
  - ⇒ good base for subsequent coatings
  - ⇒ suitable to match fair faced concrete

3. EPOCEM MORTARS,THE NEW PRODUCT TECHNOLOGY

The majority of the listed requirements could not be met by traditional cement mortars (above all low shrinkage, high bond strength, impermeability). Modified cement mortars and resin based mortars are therefore widely used for concrete restoration work. The products available in the market can be classified according to their binder system as follows: (Fig.1)

Binder-system	Cement		Resin	Epoxy-Cement
De-signation	CC = Cement-Concrete	PCC = Polymer-Cement-Concrete	PC = Polymer-Concrete	ECC = Epoxy-Cement-Concrete
Reaction me-chanism	Ordinary cement mortars	Cement mortars modified with non-reactive polymerised thermoplasts	Mortars with reactive two component resin-hardener binders	Cement mortars with a second reactive epoxy binder. Duobinder system with hydration of cement and polyaddition of the epoxy resin.
Examples		PVA, PVP, SBR, AC	EP, PMA PUR	
Positive cha-racteris-tics	Similar to concrete	Bond (wet substrate) ↑ Impermeability ↑ E-Modulus ↓ Shrinkage ↓	Bond (dry substrate) ↑ Strength ↑ Chemical resistance ↑ Curing ↓	ECC = sum of the positive characteristics of cement and resin binders.

Fig.1 Classification of repair mortars according to their binder system

Water absorption, when permanently exposed to water, is the only disadvantage of PCC worthwhile mentioning. Their numerous advantages predominate by far and this type of mortar is now widely used for concrete restoration work.
PC certainly does have positive properties. However, reservations have to be made about bond to moist substrates and elasticity properties depending on temperature, which leave this type for special applications only.

ECC combines the positive chemical and mechanical properties of epoxies with the good physical properties of cement.

The hardening process of ECC, unlike PCC, comprises two separate chemical reactions

Hydratation of cement with water	+	Polyaddition of the epoxy resin/hardener component

To attain the combined effect of the two fundamentally different binder systems, it is extremely important that the epoxy resin forms inside the binder matrix a lamellar framework, into and through which the cement crystals can grow. (Fig.2) In case of cement crystal failure under load, the stresses transfer to the epoxy resin structure. The formation of such framework depends on the quantity, the type and above all on the dispersion of the epoxy resin in the mortar.

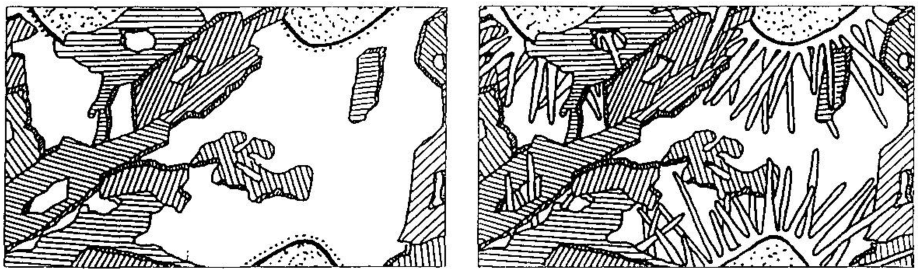

Fig.:2 Reaction mechanism in an EpoCem mortar. [2]

First generation ECC (since 1982) had considerable disadvantages such as excessively long mixing time, inhomogenious dispersion of the epoxy in the mortar, entrapped water triggering off secondary reactions causing shrinkage and unwanted stresses in the binder matrix. All this created problems on site.
Since 1987, the second generation EpoCem mortars allow easy and safe application and react without any problems.[2] These products are based on finely tuned binder systems. Selected additives, ideal grading of the aggregates for the powder component, specially developed, in water emulsifiable, high reactive polyamine hardeners and a super finely dispersed binder emulsion allow problem-free application on site.

Practical experience in the last 5 years has shown the strong points of this new product technology for restoration of reinforced concrete bridges as follows:

- **Superior bond to mineral substrates ,even when permanently moist.**
- **Low-shrinkage hardening and accelerated strength development allow easy finishing.**
- **Time saving because surfaces can be coated after 1 to 3 days.**
- **High compressive and flexural strength with E-modulus and thermal expansion similar to cement mortar.**
- **Impervious to water but pervious to water vapour.**
- **High resistance against freeze-thaw cycles and de-icing salts.**
- **Economical thanks to easy and quick application.**

Numerous successful applications are there to prove that the difficulties, met with the ECC of the first generation, have been overcome. EpoCem mortar has excellent self-levelling properties and is therefore widely used for re-bar corrosion protection or as a thin-layer overlay for bridge deck restoration work. EpoCem can be thyxotropised for vertical and overhead application.

4. RESTORATION UNDER DYNAMIC LOAD

New materials and their optimal use have led, in the recent time, to slenderer structures and wider spans which in consequence are more sensitive to deformation and vibrations. Bridge restoration work very often has to be executed under full or at least partial traffic load in order to limit the obstruction of traffic and avoid excessive costs for a temporary bridge. Repair mortars for work on the underside of a bridge have therefore to meet additional requirements.

Fig. 3a) Inertial force **F** Fig. 3b) Alternate elongation

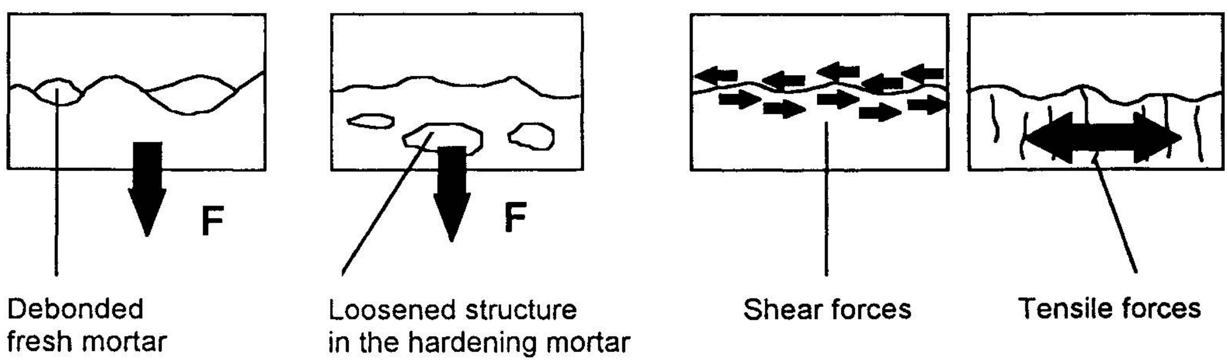

Fig.3: Effect of a dynamic load on the repair mortar. [3]

- **Inertial forces, resulting from vibrations, act on overhead applied repair mortar besides its proper weight, and can cause the mortar to detach from the substrate or loosen up the structure of the mortar in process of hardening.** (Fig.3a)
- **The substrates alternate deformations cause shear forces, which impair the bond between mortar and old concrete, as well as tensile forces in the mortar, which can cause cracking.** (Fig.3b)

The frequency of the oscillations is affected by the characteristic frequency of the bridge as well as by the frequency of the oscillation imposed by traffic. Records or Standard Specifications of such oscillation characteristics are practically non-existent. The test methods applied by two different test laboratories are described in chapter 5 and 6.

Basically there are two ways to apply non-sag mortar overhead:

A - Hand application of ready for use repair mortars for smaller patches.

B - Machine application, wet spray or dry spray, of ready for use mortar mixes for restoration of large areas. Both spraying methods are commonly used and the decision which one to chose is rather influenced by application criteria than by the pros and cons of different materials technologies. The main advantages are listed below:

Dry spray method	Wet spray method
• High output	• Consistent w/c ratio
• No bonding bridge necessary	• Low dust nuisance
	• Low rebound
• Thicker layers	• Easy finishing

5. DYNAMIC TESTING OF MACHINE APPLIED DRY MIXES.

The Structural Engineering Laboratory (IBAC) in Aachen, Germany uses a standardized method for the testing of repair mortars under dynamic load. The test is based on the ZTV-SIB 90 plus Annex TP BE-SPCC.[4] The loading pattern is specified as follows:
A beam (0.2 x 0.75 x 2.45 m) oscillates for 24 hours at a frequency of f=10Hz and with an oscillation velocity of v=8.5 mm/s in a way that a maximum tensile stress of $\sigma_{Z,R}$ = 1.5 N/mm^2 results in the contact zone between concrete and mortar.
The loading is controlled in a way to produce consistent elongation amplitudes in the contact zone. The testing is very comprehensive and includes different basic tests as well as quality control tests of the materials used for the repair system (i.e. compressive strength, tensile bending strength, shrinkage, E-modulus etc.). Various Standards specify the ultimate requirements depending on the function of the mortar in its intended use and on its method of application. Polymer modified mortars (SPCC) spray applied, have to meet the following specification:

- Pull off strength after oscillation: $\bar{\beta}_{HZ} \geq 2.0$ N/mm^2
  $\beta_{HZ\ min.} \geq 1.5$ N/mm^2
- Maximum crack width: ≤ 0.1 mm

Specific formulations of polymer and silica fume modified mortars for sprayed application, meeting these exacting specifications for repair under dynamic load, are available from the market since several years already. Remains open the question in how far the load pattern chosen for these tests are representative of the various shapes and characteristics of our bridges. It has nevertheless to be mentioned that all restoration work executed with mortars having passed above test, has been proven successful so far.

6. DYNAMIC TESTING OF HAND APPLIED READY FOR USE MORTARS

The Swiss Federal Research and Materials Testing Laboratory EMPA in Dübendorf, in 1994 have tested 10 different standard PCC and ECC products (some of them with fibres) available from the market on an oscillating beam.[3] Based on results gained in the field from 202 bridges, the frequency and velocity of the oscillation have been fixed at f=5Hz and v=20mm/s. The mortar on the oscillating beam has been tested for 24 hours. Reference samples have previously been applied to the static beam. High strength prestressed concrete beams (0.2 x 0.75 x 5.65m) have been used to prevent cracking of the contact surface mortar/concrete at the maximum tensile stress of $\sigma_{Z,R}$ = 1.5 N/mm^2.

The following variables have been measured:

- **Compressive and tensile bending strength of separately prepared specimens.**
- **Bond strength on 96 carrots Ø50 mm per product.**
- **Type of failure classified according to its position (in the concrete, in the mortar, in the bond line).**
- **Visual check for cracks.**

All products have been applied by their suppliers. The test results were the following:

- The statement "High tensile bending strength = High bond strength" has been found to be valid practically without exception.
- Only 2 out of 10 products reached as well on the static as on the oscillating beam a bond strength > 3 N/mm^2. Both these products showed no drop in bond strength under dynamic load.
- 5 out of 10 mortars lost up to 50% of their bond strength under dynamic load. 3 products had to be eliminated due to widely scattered results (probably due to irregular application).

<u>Conclusions:</u>

Only 2 out of 7 tested mortars could be retained for recommendation after the tests under dynamic load although all mortars had performed similarly good on separate static test specimens. Both retained mortars had suffered no loss of quality on the oscillating beams. No cracking could be detected in the mortar. Both products are of the PCC type applied on a PCC respectively a ECC bonding bridge.

In order to gain assurance that application on site can be done economically, 4 selected products have been spray applied by machine and have been tested in the same way in a second test series. First results of these tests will be available at the time of the Symposium. Within the next two years, it is planned to test in a third step the best repair mortars under different relevant load conditions.

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