# ReBuild

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## STRENGTHENING OF CONCRETE ELEMENTS Part-1

Dr. Fixit Institute
of Structural Protection & Rehabilitation

A Not-for-Profit Knowledge Centre

# From the Editor's Desk

The report "Concrete Repair Mortar Market by Type (Polymer-Modified Cementitious Mortar and Epoxy-Based Mortar), Application Method (Manual, Spraying, and Pouring), End-use Industry (Building & Car Park, Road & Infrastructure, Utility) - Global Forecast to 2021", forecasts that the market size of concrete repair mortars is estimated to grow from USD 1.69 Billion in 2015 to USD 2.62 Billion by 2021, at a CAGR of 7.67%, in terms of value. However, no such exact data is available for concrete repair industry in India. But as per the report of "Industry Reports, Primary & Secondary Research," the share (% of total value) in construction chemical products in India is as follows: Admixtures: 42%, Waterproofing: 14%, Flooring: 14%, Repair & rehabilitation: 12% and misc. products: 18%.The repair industry is still being managed mostly in an unprofessional way, though the various repair products are available in the market. This is because of poor knowledge in new polymeric repair materials and continuing the old traditional cement-based repair systems rather than using advanced repair materials. Considering this weakness, we have dedicated our next few issues of ReBuild on repair and strengthening of concrete elements for our readers' benefit.

The polymer-modified cementitious (PMC) mortar segment has been witnessing significant demand in recent years due to several advantages of polymer modification, such as high workability, tensile strength, adhesion, and so on. Furthermore, the demand of PMC mortar is fueled by its low cost and environmentally friendly nature. The PMC mortar segment accounted for the largest market share in India, both in terms of volume and value, in 2015. On the other hand, epoxy-based mortars are used in extremely high strength requirements; therefore, it has a limited application in the concrete repair industry.

The repair and rehabilitation is a highly unexplored and underdeveloped market. Retrofitting is basically addition of new technology or features to older systems and improving the structures with energy efficiency. Rehabilitation is reconstruction of the structural components that were damaged. These products include cementitious repair mortars, concrete floor repairing systems, polyester and epoxy-based resin mortars, moisture insensitive epoxies, structural additives, synthetic adhesives, rust removers and corrosion inhibitors. The main rehabilitation methods are concrete jacketing, steel jacketing, and FRP wrapping.

A building constructed with different types of materials ages like the human body and therefore needs repair to strengthen its weaker members and to increase the service life of the deteriorated/ damaged structure. Materials like steel and concrete deteriorate due to gradual ingress of moisture and aggressive chemicals, weakening the structure. A structure, which is poorly constructed, will deteriorate very fast as compared to properly constructed structures. Besides, unplanned structural modifications, in adequate joint treatment, poor waterproofing systems are other causes of damages that weaken the structure and therefore need repairs and strengthening.

Concrete repair must successfully integrate the new repair materials with old materials forming a composite one capable of enduring the exposure of the environment and time. Concrete structure requires routine repair & maintenance, ranging from simple protective coating to repair of spalled concrete to strengthening the components from time to time.

The various factors that may require repair are:

- Bad quality materials.
- Poor construction practices.
- Settlement of foundation.
- Chemical attack.
- Poor maintenance.
- Structural modifications.
- Fire or natural calamities like earthquakes.
- Lack of repair & maintenance.

With respect to planning of repair, generally it should be distinguished between defects in concrete and defects caused by reinforcement corrosion. The purpose of the main assessment before repair as follows:

- To identify the cause or causes of defects.
- To establish the extent of defects.
- To establish where the defects can be expected to spread to other parts of the structure.
- To assess the effect of defects on structural safety and stability.
- To identify all locations, where protection or repair may be needed.

The following options shall be taken into account in deciding the appropriate action to meet the future requirements for the life of the structures:

- Do nothing for a certain time and monitor the structures for active crack if any.
- Re-analysis of structural capacity, possibly leading to downgrading of the function of the structure.
- Prevention or reduction of further deterioration, without improvement of the concrete structure.
- Improvement, strengthening or refurbishment of all or parts of the concrete structure.
- Reconstruction of part or all of the concrete structure.
- Demolition of all or part of the concrete structure.

"Concrete Repair Guidance Notes 1-11" of Concrete Society UK gives guidance for repair and strengthening of structures confirming to European Standard on protection and repair of concrete structures i.e. "Standard EN 1504". We have referred to those principles and methodologies as outlined in the standard. The detail repair materials and methodologies will be discussed in next few issues of our ReBuild.

# Repair Guidance Notes

[Excerpts from Repair Guidance Notes 1-11 published in CONCRETE UK; May 2007 pp.13-14, June 2007 pp.16-17, July 2007,pp.9-10, August 2007 pp. 9-10,September 2007 pp. 13-14,October 2007 pp. 6-7]

The aim of these Notes is to guide consultants and contractors through the application of "Repair Standard EN 1504" and other related concrete repair standards for the evaluation, design specification and concrete repair process.

## 1.0 Background

There are a number of causes of deterioration in concrete buildings and structures. Even when they are adequately built,properly used and well-maintatined, the environment will affect a structure and components will degrade or wear out. The largest single cause of deterioration in reinforced concrete structures is corrosion of the reinforcing steel. In addition, there are number of deterioration process that attack the concrete directly, some from processes within, such as alkali-silica reaction, and some from external sources, such as ingress of chloride ions from atmosphere.Some are realted to initial construction problems while others are due to subsequent use or lack of maintenance of the structure.

This section summarises the major causes of defects,damage and decay in concrete buildings and structures; any attempt to remedy problems must start with a through understanding of the cause and extent of the deterioration. It is essential that a detailed investigation is carried out as part of the appraisal process, the results are interpreted and their repair options fully evaluated to ensure that the right repair option is selected. Carbonation and chloride attacks are two major causes of reinforcement corrosion. It is not required to address the corrosion mechanism here but to understand their significance in rapid deterioration of reinfoced concrete structures.

## 2.0 Degradation of Concrete

### 2.1 Design and Construction Defects

It is very much important to take care of 5 C's such as constutients, cover, compaction, curing and coating during concrete construction and further protection for the duarbility of the reinforced concrete structures. The deterioration takes place due to following factors:

- Constituents: Improper concrete constituents, high water-cement ratio, cast in chlorides, alkali-aggregate reaction
- Cover: Poor cover to the reinforcement
- Compaction: Poor compaction leading to honeycombing and voids
- Curing: Improper curing
- Coating: Absence of protective coating in aggressive environment

Concrete degradation also takes place due to alkali-aggregate reactivity, sulphate attack, high-alumina cement concrete and chemical attack.

### 2.2 Causes for Structural Damage

- Inadequate design
- Settlement or other ground movement
- Overloading or change of use
- Fire
- Impact
- Seismic effects
- Wind

## 3.0 Fixing Concrete

There are many mechanisms that can affect plain, reinforced and prestressed concrete structures. The mechanism will produce deterioration in one or more forms:

- Corrosion of reinforcement or unsheathed prestressing stand
  - Visible damage (cracking, spalling, rust staining)
  - Hidden damage (delamination, reduction in cross-section of reinforcement)
  - Non-visible and potential defects
- Corrosion of post-tensioning bar or strand within ducts
  - Hidden corrosion within the duct, unlikely to result in visible damage
- Damage to the concrete
  - Carbonation or ingress of chlorides
  - Acid or sulphate attack of the cement matrix
  - Abrasion or impact damage
  - Fire

Following the diagnosis and quantification of the extent of damage, repairs will have to be undertaken. These general principles of repair include:

- Treating exposed steel.
- Filling holes left by the removal of spalled or damaged concrete.
- Arresting and preventing further degradation.
- Strengthening of weakened structures.

All repair works should be carried out with repair products and systems specifically formulated for the intended purpose, with appropriate quality control and performance certification in place, such as compliance with the standard comes into force.

### 3.1 Arresting degradation

The purpose of the repair will be to ensure that significant deterioration does not occur in the future. Sometimes this is simply the removal of the cause and replacement of damaged concrete. Where corrosion of reinforcement is involved, the planning process requires significantly more consideration.

The two main initiators of reinforcement corrosion are carbonation and chloride ion. To arrest deterioration, these must be removed or neutralised.

#### *3.1.1 Carbonation*

All areas of concrete where the depth of carbonation exceeds the depth of cover will potentially be able to corrode in the presence of moisture and oxygen. The repair strategy must include breakout and removal of all carbonated concrete in contact with the reinforcement, or provide an alternative strategy where corrosion of the reinforcement is prevented (eg, corrosion inhibitors, moisture-excluding surface coatings, electrochemical realkalisation of the cover concrete).

#### *3.1.2 Chloride*

All areas of concrete where the free chloride ion content of concrete at the reinforcement depth exceeds 0.2% by weight of cement (typically taken to be 0.4% for chloride salts penetrating from the environment and 1.0% for chloride cast in to the concrete) will potentially be able to corrode in the presence of moisture and oxygen. The repair strategy must include breakout and removal of all chloride-contaminated concrete in contact with the reinforcement, or provide an alternative strategy where corrosion of the reinforcement is prevented (eg, corrosion inhibitors, catholic protection, electrochemical chloride extraction of the cover concrete).

#### *3.1.3 Combined Carbonation and Chloride*

It is rare for carbonation and penetrating chloride to occur coincidently. However, it is more common to find carbonation of older buildings where the concrete contains cast-in calcium chloride. The process of carbonation releases more free chloride ion which can push the free chloride ion content above the limit of 0.2%, initiating corrosion over time. The repair strategy is the same as for chloride above.

### 3.2 Minimum Requirements before Work Begins

Six options are commonly used, singly or more often in combination, for effective concrete repair:

- Do nothing but monitor
- Reanalyse the structural capacity of the weakened element
- Prevent or reduce further deterioration
- Improve, strengthen or refurbish all or part of the structure
- Replace all or part of the structure
- Demolish – completely or partially

The pre-repair assessment should include of the following:

- Original design approach
- Condition during construction
- History of the structure
- Client's current requirements
- Approximate extent and likely rate of increase of defects (without repair)
- Importance of whole life costing of the works, which is strongly recommended as the basis for selecting the final repair strategy, looking at the value over the intended remaining life of the structure, rather than just the capital costs of the works.

As part of this assessment, full consideration is required of safety and structural implications arising from the present and future condition of sub-standard structures in need of repair.

#### *3.2.1 Residual Structural Capacity*

Structural weakening needs very careful consideration by engineers experienced in the repair process:

- Weakening at the point of repair (eg,due to loss of concrete section in a compression member, or lose in cross-section of reinforcing bar due to corrosion), can be calculated through a standard structural appraisal to give the residual structural capacity.
- Weakening post-repair is less obvious and the following factors must be considered:
    - The physical and structural properties of the repair products and systems to be used at the applicable service temperature, in particular the elastic modulus, creep and shrinkage of the materials; where the repair is to take compressive loads, consider the effects of creep at elevated service temperature.
    - Locked-out stress' occurs when tensioned reinforcement is broken out and repaired, thereby losing its tensioned state: this weakening effect can only be reduced by removing load from the structure prior to repair (eg,propping and load restrictions) and/or minimising the area of concrete to be broken out, even if new bar is added to replace the bar sectional area lost due to corrosion.
    - Maximum service temperature of structural repair materials – some organic materials, such as epoxy resin and other adhesives, may have a glass transition temperature of less than 60 degree C meaning that they are unsuitable for structural use if service temperature exceeds this value.
    - Treatment of prestressed structures needs particular care, as the repair work will need to ensure the full structural capacity of the elements can be de-stressed and then re-stressed, pre-tensioned elements are often replaced owing to the difficulty or providing repaired element with the same structural capacity as the original.

### 3.3 Treating Exposed Reinforcing or Prestressing Bar

Corroded steel must be carefully assessed for loss of cross-sectional area. With conventional reinforcement, significant corrosion can occur without significant weakening of the structure, but with prestressed strand, even slight pitting corrosion can cause significant weakening. Preparation by grit blasting or high-pressure water jetting (at least 700 bar) is preferred as this will remove all corrosion product and contaminants. Generally, further treatment of the bar is not necessary where it is to be surrounded by a strongly alkaline repair material. However, many repair products are not compatible with the concrete initially used (eg, materials are often formulated to be stiff, suitable for trowel application, rather than a free-flowing concrete and may not full encapsulate the reinforcement). Also the matrix may not be cementitious at all, but be based on an epoxy or rather resin system that will not passivate the reinforcement. Therefore, most concrete repair products and systems include primers for the reinforcement.

### 3.4 Filling Patch Surfaces

It is strongly recommended that the patch surfaces left following removal of defective concrete are filled using materials that are of similar physical and chemical properties to those they are replacing, particularly where the material is in contact with the reinforcement. Therefore, cementitious concrete repair products should normally be used unless there are over riding technical reasons to use other binder formulations (eg. epoxy or polyester resin).

Repair materials fall into three basic categories:

- Structural – where the repaired element is to be under compressive load. Materials are usually based on normal density cementitious products, modified with additives to reduce shrinkage and improve adhesion but still retaining comparable elastic modules, creep and shrinkage to that of the concrete it replaces. Note that while the laboratory tests for product may suggest suitability for structural applications, each specific repair situation must be considered on its merit (eg. compare the properties of old concrete that has completed full shrinkage and creep under compression, with new material that will have finite shrinkage and creep in the repair situation)
- Semi-structural – where the repair product is in contact with reinforcement but is under no direct compressive load, such as repair to beam soffit. Materials are usually based on lightweight cementitious products that are unlikely to have the same elastic, creep and shrinkage as concrete.
- Cosmetic – where the hole does not extend to the depth of the reinforcement. Materials are usually based on lightweight products, with either cementitious or polymer binder, and are unlikely to have the same elastic modulus, creep and shrinkage as concrete.

Most repair products and systems in this category will include a priming system to promote adhesion with the existing concrete. Such ‘bonding aids’ must be used strictly in accordance with the manufacturer’s instructions and in particular the time between applying the bonding aid and applying the repair mortar must be strictly followed for the ambient temperature, humidity and wind conditions.

### 3.5 Preventing Further Degradation

To prevent future degradation, measures must be put in place to stop the initiator of degradation. In most repair situations, the durability of the concrete can be significantly enhanced by use of a surface protection system. The exact performance requirements of the surface protection system will depend on the conditions of exposure and mechanism at work.

### 3.6 Strengthening of Weakened Structures

Strengthening may be required where structures are assessed to be below their original structural capacity. Methods include:

- Adding extra reinforcement and casting additional concrete.
- Adding extremely bonded reinforcement to increase tensile and/or shear capacity.
- Adding external post-tensioning.

Where structures are strengthened, the ambient service temperature and possible fire effects need to be carefully considered along with the design principles of the strengthening. As mentioned above, the glass transition temperature of resins used to bond steel or synthetic fibres to concrete may be relevant, particularly in a fire situation.

## 4.0 Framework of Whole Repair Process

The principles and methods of repair are derived into two groups; the first deals with defects in concrete as a material, the second addresses defects caused by corrosion of the reinforcement. Table 1 summarises the process of assessment, specification, site execution and maintenance and monitoring of structures and Table 2 summarises the repair principle.

**Step 1:** Assess Damage

- Present condition
- Original design approach
- Environment and contamination
- Conditions during construction
- Conditions of use
- History of structure
- Future use

**Step 2:** Choose Options

- Considering intended use, design life and service life
- With the required performance characteristics
- Likely long-term performance of protection or repair works
- Opportunities for additional protection and monitoring
- Acceptable number and cost of future repair cycles
- Cost and funding of alternative protection or repair options, including future maintenance and access costs
- Properties and methods of preparation of existing substrate

- Appearance of protected or repaired structure

**Step 3:** Choose Repair Principle(s)

Defects in concrete

- Protection against ingress
- Moisture control
- Concrete restoration
- Structural strengthening
- Physical resistance
- Resistance to chemicals

Reinforcement corrosion

- Preserving or restoring passivity
- Increasing resistivity
- Cathodic control
- Cathodic protection
- Control of anodic areas

**Step 4:** Choose Method (s)

- Appropriate to type and cause for combinations) and extent of defects
- Appropriate to future service conditions
- Appropriate to protection or repair option chosen
- Compliance with the Principle chosen
- Availability of products and systems complying with relevant standards

**Step 5:** Choose Materials

- Minimum performance characteristics for all intended uses
- Minimum performance characteristics for certain intended uses
- Performance characteristics for specific applications

**Step 6:** Specify Ongoing Requirements

- Record of the protection or repair works that have been carried out
- Instructions on inspection and maintenance to be undertaken during the remaining design life to the repair part of the concrete structure.

The requirement for quality control of the repair works covering testing to verify the suitability of the substrate before repair and quality control tests and checks carried out during and after repair should be specified.

The minimum performance standards of the repair material for a range of engineering properties, related to end use should be established. For example, a surface protection system for concrete, such as film-forming paint, will have different performance requirements depending on whether it is intended to protect against ingress of chloride ions, or reduce carbonation of the concrete, or control moisture penetration into the surface, and whether the paint is to be applied over active cracks in the concrete.

**Table 2:** Principles and methods for protection and repair of concrete

| Principle | Examples of Methods based on the Principles |
|---|---|
| Protection against ingress | Hydrophobic impregnation<br>Impregnation<br>Coating (including crack-bridging)<br>Filling cracks<br>Transferring cracks into joints<br>Erecting external panels<br>Applying membranes |
| Moisture control | Hydrophobic impregnation<br>• Coating (including crack-bridging)<br>• Over cladding<br>• Electrochemical drying treatment |
| Concrete restoration | Hand applied mortar<br>Recasting with concrete<br>Sprayed concrete<br>Replacing elements |
| Structural strengthening | • Adding or replacing embedded or external reinforcing bars<br>• Adding reinforcement anchored in pre-formed or drilled holes<br>• Bonded plate reinforcement<br>• Adding mortar or concrete<br>• Injecting cracks, voids or interstices<br>• Filling cracks, voids or interstices<br>• Prestressing – (post-tensioning) |
| Increasing physical resistance | Overlay or coating<br>Impregnation |
| Resistance to chemicals | Overlay or coating<br>Impregnation |
| Preserving or restoring passivity | Increasing cover with additional mortar or concrete<br>Replacing contaminated or carbonated concrete<br>Electrochemical realkalisation of carbonated concrete by diffusion<br>Elecctrochemical chloride extraction |
| Increasing resistivity | Hydrophobic impregnation<br>Coating |
| Cathodic control | Limiting oxygen content (at the cathode) by saturation or surface coating |
| Cathodic protection | Applying an electrical potential |
| Control of anodic areas | Active coating<br>Barrier coating<br>Applying inhibitors to the concrete |

### 5.0 Surface Protection Systems

The use of coatings and waterproofing systems as part of a repair strategy is becoming increasingly common. These not only provide an enhanced appearance but also an enhanced durability. This repair Note presents a brief introduction to coating concrete, including a review of the relevant Standard EN 1504 Part 2.

### 5.1 Surface Treatments for Concrete

Anti-carbonation represents a widely used and relatively well known family of systems for enhancing the durability of reinforced concrete. Historically, there have been two basic figures expressed for such coatings: an R value denotes the resistance to carbon dioxide and an $S_d$ value denotes the vapour permeability. Silanes are also fairly common place as surface treatments for concrete; as are waterproofing systems that either sit on the surface of the concrete or soak into the concrete and block the pores. These are the commonest types of treatments, and are technically termed hydrophobic impregnations, impregnations of coatings.

In applying surface treatments to concrete, it is necessary to remember a number of key elements. Concrete is a porous material. The pores may contain air or moisture; consequently, anything applied to the surface will need to be able to cope with this. The moisture may be present near to the surface but will also be present at depth in the concrete. It is likely that the concrete to be treated will be external and therefore may be exposed to water just before, during or after the application and this needs to be considered in selecting a material. Some surface treatments are more able to cope with the presence of moisture than others. Urethanes have excellent adhesion and crack bridging properties but can turn into expanding foam if applied in the presence of moisture and so are often used in conjunction with a water-borne epoxy primer, which will be applied to the surface as a sealant.

The moisture may also contain significant quantities of soluble salts. Coatings and surface treatments are therefore often termed 'breathable', where they will allow the passage of water vapour out of the concrete but will not allow liquid water to penetrate. This ability to 'breath' prevents blistering due to water pressure and can allow the concrete to dry out. However, where significant amounts of soluble salts are present this can cause the salts to recrystallize and break-up the surface of the concrete under the coating system.

Concrete also contains cracks. These can be the result of its structural behaviour, thermal stresses during the original casting, or long-term shrinkage of the concrete. They can be subject to short-or long-term movements and an uncracked area can develop cracks as time progresses. Technically, any coating covering cracks that appear from nothing is subject to infinite strain, which makes for interesting calculations for required structural properties.

Finally, as with any surface treatment to any substrate, the condition of the surface needs to be considered. Some surface preparation will be required for any structure. The type and nature of the preparation will depend on the material to be applied. Conversely, the suitability of the material depends on the practicality of achieving this required level of surface preparation as well as process of applying and curing the material.

### 5.2 Surface protection systems

There are three basic approaches used in applying surface protection to concrete.

- Hydrophobic impregnation (H) – These materials penetrate the concrete and leave a water – repellent lining on the surface of the pores. They encourage the concrete surface to shed water but do not prevent water ingress under significant pressure.
- Impregnation (I) – these materials impregnate the concrete and block up the pores.
- Coatings (C) – coating system are those that adhere to the outer surface of the concrete.

## 6.0 Mortars, Structural Adhesives and Other Repair Products

### 6.1 Repair Mortars

Repair mortars and concretes for the structural or non-structural repair of concrete, to replace defective concrete and to protect reinforcement, in order to extend the service life of a concrete structure exhibiting deterioration. They may be used in conjunction with other products. Repair mortars and concretes are used for several repair application as shown in Table 3.

**Table 3:** Repair using mortars and concretes

| | |
|---|---|
| Concrete restoration | Applying mortar by hand |
| | Recasting with concrete |
| | Spraying mortar or concrete |
| Structural strengthening | Adding mortar or concrete |
| Preserving or restoring passivity | Increasing cover to reinforcement with mortar or concrete |
| | Replacing contaminated concrete |

#### *6.1.1 Overview of Requirements*

The performance requirements for repair mortars and concretes are:

- Compressive strength
- Chloride ion content
- Adhesive bond
- Restrained shrinkage/expansion
- Carbonation resistance
- Thermal compatibility
- Elastic modulus
- Skid resistance
- Coefficient of thermal expansion
- Capacity absorption (water permeability).

Repair mortars and concretes are categorised into structural repair and non-structural repair work. Structural mortars and concretes are distinguished by having a high compressive strength, stronger adhesion to the substrate, before and after thermal cycling and shrinkage tests, and requirements for the elastic modules of greater than 15/20 GPA.

## 6.2 Structural Bonding

The products intended for application to concrete should provide a durable structural bond to an additional applied material, such as carbon fibre plates, steel or concrete, including:

- Bonding external plates to the surface of concrete for strengthening purpose.
- Bonding hardened concrete to hardened concrete in repair and strengthening situations.
- Casting of fresh concrete to hardened concrete using an adhesive bonded joint where it forms a part of the structure and is required to act in a composite manner.
- Structural bonding products are used for structural strengthening in particular for bonded plate reinforcement and for bonding mortar or concrete.

### *6.2.1 Overview of Requirements*

The performance requirements address the following performance aspects of the materials:

- Suitable for application, including to vertical surfaces and soffits, horizontal surfaces and by injection
- Temperature range of suitability for application and curing and suitability for application to a wet substrate.
- Adhesion of plates to plates, concrete and corrosion protected steel and of hardened or fresh concrete to hardened concrete
- Durability of the complete system under thermal or moisture cycling.

The following characteristics of the bonding material should be considered

- Open time and workable life
- Modulus of elasticity in compression and flexure
- Compressive and shear strength
- Glass transition temperature
- Coefficient of thermal expansion
- Shrinkage

The detailed performance requirements, specified test methods to be used, and sets out the quality control and conformity evaluation requirements that materials producers need to follow when producing products to meet the standard.

## 6.3 Concrete Injection

The products intended for filling of cracks, voids and interstices in concrete on injection method should be based on either a hydraulic binder or a polymer binder, and different products characteristics are specified for different materials. Injection used to avoid the harmful consequences of voids and cracks in concrete, to achieve impermeability and watertightness; to avoid penetration of aggressive agents that might induce corrosion of steel reinforcement, and to strengthen the structure by strengthening the concrete.

### *6.3.1 Overview of Requirements*

The primary performance characteristics of injection products are:

- Basic characteristics, related to adhesion, shrinkage, compatibility with steel and concrete, glass transition temperature and water tightness. These are essential for any intended use.
- Workshop characteristics, which indicate the conditions in which the products can be used (width, moisture state of the crack).
- Reactivity characteristics including the workable life and strength development.
- Durability of the hardened product under the prevailing climate conditions.

Other characteristics may need to be considered for certain intended uses of the product, such as:

- Glass transition temperature, where the temperature of the hardened product in the crack may be higher than 21 degree C and the product is formulated with reactive polymer binder.
- Chloride content and corrosion behaviour for injection of reinforced concrete
- Water tightness for waterproofing injection.

## 6.4 Anchoring

Anchoring is used for adding reinforcement anchored in preformed or drilled holes in concrete in structural strengthening method. Anchoring products may include hydraulic binders or synthetic resins or a mixture of these, installed at a fluid or paste consistency, to grout reinforcing steel bars in hydraulic concrete structures.

### *6.4.1 Overview of Requirements*

The primary performance characteristics of anchoring products are:

- Pull-out resistance
- Chloride ion content
- Glass transition temperature
- Creep under tensile load

## 6.5 Reinforcement Protection

- The part 7 of Standard EN 1504 covers active coatings and barrier coatings for production of existing steel reinforcement in concrete structure under repair.

### *6.5.1 Application*

Reinforcement protection is covered by control of anodic areas:

- Active coating of the reinforcement
- Barrier coating of the reinforcement.
- This covers the use of coatings on the reinforcement; whether to provide protection or to provide a base layer to which repair mortar or concrete can subsequently be added.

### *6.5.2 Overview of Requirements*

The primary performance characteristics of anchoring products are:

- Corrosion protection
- Glass transition temperature
- Shear adhesion (of coated steel to concrete)

## 6.6 Achieving Successful Repairs

The objective is to assess the concrete repair projects by determining appropriate materials selection and executing the work, taking the whole-life cost of the repair system into account. While designing the repair system following provisions should be made:

- Structural stability during repair work
- Aesthetic performance of the repair
- Concrete removal considering health, safety & environment

## 6.7 Performance-based Repair & Rehabilitation

The durability and longer-term performance of repaired concrete structures is a key issue in any repaired project. The repair should be performance-based rather than perspective based approach. It is postulated that the management of concrete structures could be improved by implementing a proactive monitoring and maintenance system rather than taking remedial intervention only after damage happens.The repair failures can be avoided provided the causes of failure of repair system are taken care which is related mainly to:

- Wrong diagnosis of the cause of initial damage or deterioration of the structure
- Inappropriate design of the intervention works
- Inappropriate specification or choice of materials used
- Poor workmanship

Reactive maintenance is likely to be instigated only when visible indications appear (eg. cracking or spalling of concrete), with an intervention being made to slow the rate of deterioration and extend the length of useful service life of the structure. Proactive maintenance, such as the early application of a coating to slow the ingress of aggressive species, could potentially delay the onset of corrosion and extend the useful service life. The implementation of this concept is illustrated in Fig. 1, which presents a time-line representation of the two alternative philosophies and includes a notional indication of their respective costs. The relative cumulative maintenance cost in case of proactive maintenance approach is less than reactive approach with better structural performance in long run whereas comparative initial cost is higher. The graph indicates that the proactive cost is evenly distributed in life time whereas the cost for maintenance in reactive approach is considerably very high during major repair.

Recently changes in owner attitudes to construction are reflected by their increasing interest in through-life costs, which is not only the capital costs of the construction but particularly in the operational costs associated with delivery of function performance for a defined life span. This change is an important development in achieving a more balance and holistic approach to extending the life span of existing buildings and structures.

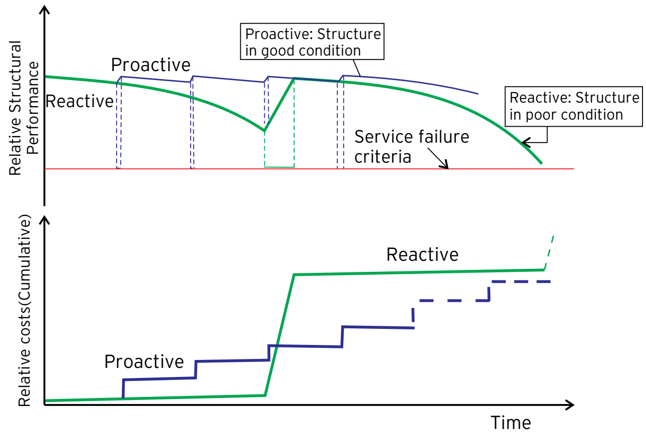


**Fig. 1:** Alternative approaches to the management and maintenance of structures

## 6.8 Ongoing Monitoring of Concrete Repairs

After completion of repair of the structure, it should be monitored by visual inspection in every two years, detailed inspection with non-destructive tests in every six to ten years and special inspection as required to inspect a particular defect. Further the building or structure should have a regime of routine maintenance to keep the structure in good order.

## 7.0 Conclusion

Understanding the cause of the defects and damages after the structural assessment the right kind of material can be specified. In following article the materials and methodologies for repair are discussed in details.

# Concrete repair

[Excerpts from Dr. Fixit Guide to Healthy Construction, Cracks & Crack Repair (Unpublished)]

### 1.0 Materials for Non Structural Crack Repair

Materials for non-structural crack repair of dormant nature should be a rigid material. The crack should be three to four times wider than the largest aggregate particle. Cementitious, polymer modified cementitious grouts of acrylic, styrene-acrylic and styrene-butadiene should be used for wider cracks. However polyester and epoxy resins should be used for injection of dormant cracks. For live cracks flexible material of polysulphide or polyurethane should be used.

### 2.0 Factors for Selection of Repair Materials

Compatibility of the repair materials with the existing substrate and durability under various conditions in service are of much greater importance. Apart from bond and compressive strength there are some other properties such as dimensional stability (Shrinkage), coefficient of thermal expansion, modulus of elasticity and permeability which should be taken care during selection of repair materials.

During repair analysis stage the following conditions and requirements need to be considered to meet the requirement while selecting a repair material. Thereafter the best available repair material may be selected considering with optimum cost, performance and risk. The conditions are:

- Load carrying requirements
- Service and exposure conditions
- User performance requirements
- Operating conditions during placement

The other factors like permeability, chemical and electrochemical compatibility should also be considered for compatibility. Final selection of the material or combination of materials must then taken into account the ease of application, cost, and available labour skills and equipment. Unless we select proper repair material & technique, repairing of the same crack will go on again and again which needs to be monitored by a digital crack measuring equipment (Fig. 1).

**Fig. 1:** Digital crack measuring gauge

### 3.0 Requirement of Properties of Repair Materials for Crack Repair

The use of cementitious, polymer modified cementitious & polymeric materials for repair of cracks has been widely accepted and most effective. A crack filling material should satisfy the requirements such as low viscosity to penetrate the crack; good workability, mix stability, ageing, resistance, strength, compatibility with substrate, adequate adhesion and low volatile content. The major properties requirements of the materials are given in Table 1.

### 4.0 Methods of Nonstructural Crack Repair

Before repair of non structural cracks the following factors have to be considered:

- Whether the crack is dormant or live.
- The width and depth of the crack.
- Whether or not sealing against pressure is required, and, if so, from which side of the crack will the pressure be exerted.
- Whether or not appearance is a factor.

### 4.1 Repair of Dormant Cracks

Dormant cracks may range in width from 0.05 mm or less (crazing) to 6 mm or more. Obviously the width of the crack will have considerable influence on the materials and methods chosen for its repair.

The fine cracks are repaired by low viscous epoxy resin and other synthetic resin by injecting. Wide cracks on a vertical surface are also repaired by injection methods. Cracks on horizontal surface can be repaired by injection or by crack filling.

Dormant cracks, where the repair does not have to perform a structural role, can be repaired by enlarging the crack along the external face and filling and sealing it with a suitable joint sealer. This method is commonly used to prevent water penetration to cracked areas.

**Table 1.** Properties of typical concrete repair materials

| Property | Polymer-resin mortar | Polymer- modified cementitious mortar | Plain cementitious mortar |
|---|---|---|---|
| Compressive strength MPa | 50-100 | 30-60 | 20-50 |
| Tensile strength MPa | 10-15 | 5-10 | 2-5 |
| Modulus of elasticity GPa | 10-20 | 15-25 | 20-30 |
| Coefficient of thermal expansion (per $^{o}$C) | 25-30 x $10^{-6}$ | 10-20 x $10^{-6}$ | 10 x $10^{-6}$ |
| Max. Service temp. ($^{o}$C) | 40-80 | 100-300 | > 300 |

The method is suitable for sealing both fine pattern cracks and larger isolated defects. Various materials are used, including epoxies, urethanes, silicones, polysulphides, asphaltic materials and polymer mortars. Polymer mortars are used for wider cracks. The crack is routed out, cleaned and flushed out before the sealant is placed. It should be ensured that the crack is filled completely. Where ever a cementitious material is being used, dry or moist crack edges must be wetted thoroughly (Fig. 2 & 3).

**Fig. 2:** Cracks are routed cleaned and prepared

**Fig. 3:** Crack filling with polymeric repair material

### *4.1.1 Cementitious Grout*

It is used for repair of cracks that are 6 mm and greater in width. It is a mixture of cementitious material and water, with or without aggregate that is proportioned to produce a pourable consistency without segregation of constituents.

Cement-based grouts are available in a wide range of consistencies; therefore, the methods of application are diverse. These materials are the most economical of the choices available for repair. They do not require unusual skill or special equipment to apply, and are reasonably safe to handle. These materials tend to have similar properties to the parent concrete, and have the ability to undergo autogeneous healing due to subsequent hydration of cementitious materials at fracture surfaces. Shrinkage is a concern in such type of grouts. These are not suitable for structural repairs of active cracks.

Steps for application of cementitious grouts are as follows:

- Generally, some form of routing and surface preparation, such as removal of loose debris.
- Prewetting to be done to achieve a Saturated-Surface-Dry (SSD ) condition.
- Grouts are generally to be mixed to a pourable consistency by using a drill and paddle mixer, and the consistency may be adjusted thereafter.
- Application should be done by hand troweling or dry packing into vertical and overhead cracks to fill all pores and voids.
- Finally, a suitable coating to be applied on the repaired surfaces.

### *4.1.2 Polymer Modified Cementitious Grout*

It is generally used to repair cracks that are 6 mm and greater in width. It is a mixture consisting primarily of cement, fine aggregate, water, and a polymer such as acrylic, styrene-acrylic, styrene-butadiene, or a water-borne epoxy. The consistency of this material may vary from a stiff material suitable for hand-packing large cracks on overhead and vertical surfaces to a pourable consistency suitable for gravity feeding cracks in horizontal slabs. These materials are generally more economical than polymer grouts, and the performance, with respect to bond strength, tensile strength, and flexural strength, are improved compared with cement-based materials that do not contain any polymers.

The potentially high shrinkage of polymer-cement grouts may make it difficult to obtain a watertight repair. These materials are chemically resistant. The steps for repair are similar as cementious grout as explained earlier.

### *4.1.3 Polyester Resin Grout*

These are very much suitable for rapid gaining of strength within a few hours. It produces a great deal of heat during the curing process but the greatest limitation on their uses is that they also shrink during the process. It's flexibility is considerably less. They have also lower bond strength and do not bond under damp condition. They are more cost effective than epoxy. Because of their speed of their setting they have extensively used in the repair of aircraft pavements. But care should be taken not to use this material in wet conditions.

### *4.1.4 Epoxy Grout*

Wider cracks, i.e. at least 3 mm or more in width, are sealed by epoxy resin. It is a mixture where the polymer, such as an epoxy resin, serves as the binder, and where sand, usually oven-dried silica with a grading from 0.8 to 0.4 mm is the filler and a curing agent some times called hardener. The curing agent selection plays the major role in determining many of the properties of the final cured epoxy. These properties include pot life, cure or drying time, penetration and wet-ability. Curing agents come in many different chemical compositions, all based on amines or amides. The consistency may vary from a stiff material suitable for hand-packing large cracks on overhead and vertical surfaces to a pourable consistency suitable for gravity feeding cracks in horizontal slabs (Fig. 4). Epoxy grouts bond extremely well to concrete and have low shrinkage, resulting in a liquid-tight repair in dormant cracks.

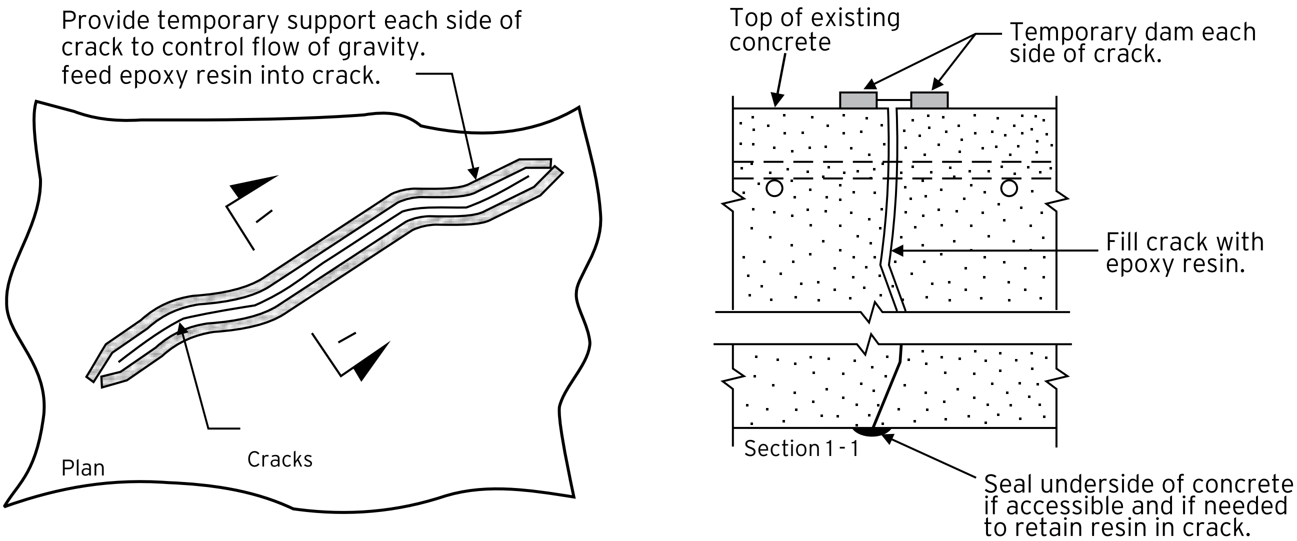


**Fig. 4:** Horizontal surface crack repair detail

*4.1.5 Other Methods*

Stitching, grouting, dry-packing and autogenous healing are all methods of crack repair that can be appropriate in certain situations. Very fine cracks, e.g. crazing, are very difficult to repair effectively and in many cases the best option may be to do nothing. Autogenous healing of very fine cracks may occur with time which is a naturally occurring process that are wet but are not subject to water flow. It works as a result of the continued hydration of the cement and the carbonation of the concrete. The precipitation, accumulation and growth of the calcium hydroxide and calcium carbonate crystals chemically bond and restore some integrity across the crack.

## 5.2 Repair of Live Cracks

Cracks subjected to movement should be treated carefully. Small movements up to 35% of crack width can be tolerated with a flexible sealant. For large crack and where rapid cycle movement is anticipated, the cracks should be treated as movement joints. The movement of such cracks has to be established before sealing with a suitable sealant. For active cracks a flexible joint sealant can be used with the help of a bond breaker (Fig. 5).

Live or active cracks must be treated as if they were control joints. It must be determined if it is necessary to restore the tensile or flexural strength across the crack. If the strength must be restored, it is best to install an expansion joint nearby prior to bonding the crack. If the crack is simply bonded, a new crack will occur adjacent to the old. Active cracks that are leaking and must be bonded is the most difficult problem. The following precautions should be taken.

First the leakage must be stopped and the crack dried. If the crack can not be dried prior to injection, other methods of strengthening should be considered, such as stitching or external stressing.

Active cracks that must be made watertight cannot be easily repaired, because they change in width in response to changes in temperature or humidity. The required seal must have the proper elongation and shape factor.

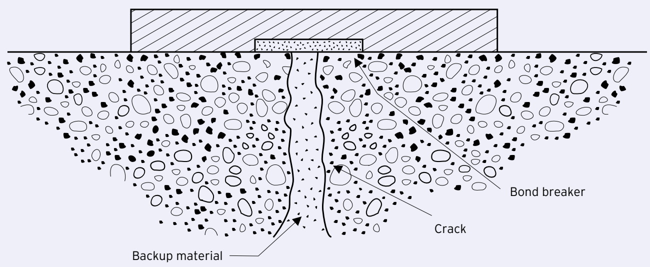


**Fig. 5:** Flexible sealing

To provide a watertight seal in a crack, the crack must be routed out to a width of at least 10 mm to provide some stretching length.

In addition, bond must be prevented to the bottom of the routed area to achieve an unbonded length.

The various methods for treating live cracks are discussed below.

*5.2.1 Flexible Sealants*

The various low cost sealants like mastics such as non-drying oils, butyl rubber, or low melting asphalts, with added fillers or fibres can be used where movement will not exceed 15% of the width of the groove and noncyclic. They are used for vertical and no traffic structures. The other thermoplastic such as asphalts, rubber-modified asphalts, bitumen. rubber-modified bitumen, pitches and coal tar are used where movement of crack is about 25% of the groove width. Although these materials soften much less than mastic, they expand at high temperature and degraded by ultra-violet rays. Elastomer sealants like poly-sulphides, epoxy poly sulphides, polyurethanes, and silicone sand acrylic are widely used because of their higher elongation.

*5.2.1.1 Polyurethane Sealant*

Polyurethane sealants (Fig. 6) are generally used to seal cracks that are from 2.5 to 50 mm in width. Polyurethane sealants generally provide an excellent bond to clean concrete and masonry surfaces, and usually do not require a primer to obtain this excellent adhesion.

**Fig. 6:** PU sealant at construction joint

The use of a primer, however, is beneficial in many applications where increased adhesion is needed or in situations where the bonding surfaces are not as well prepared as is desirable. Polyurethane sealants can provide a service life from 3 to 10 years; one reason is their ability to relieve the stress at the bond line, caused by constant elongation of the joint, through controlled internal flow. Very high elongation properties make these materials suitable for active joints. Polyurethane sealants have excellent weathering resistance properties; thus, they will maintain their original material properties over time. Certain formulations of these materials may be placed in submerged environments, such as joints within water tanks and reservoirs, because their physical properties will be unaffected, even under constant immersion.

These materials do not require a high level of skill to apply. Coatings may be applied to some polyurethane sealants for a more uniform appearance, particularly in wall panels of a building.

Sealants are not suitable for structural repairs. While the chemical resistance is generally not as good as an epoxy, some sealants with enhanced resistance are available; sealant manufacturers should be consulted regarding the suitability of specific sealants for specific exposures. Although the performance of the material is not unusually affected by UV light, the surface will tend to form a white, dusty deposit on the sealant surface (known as chalking) under long-term exposure. For optimum performance, polyurethane sealants should have regular inspections and maintenance.

Proper design of the joint and sealant profile is critical to ensure the sealant performs as specified. A single direction of joint movement is usually required for good sealant performance, and bond breakers within the joint are frequently used to allow the sealant to contract vertically when stretched horizontally (just as a rubber band gets thinner when stretched). Stress buildup in the sealant is minimized as the width-depth ratio approaches 2:1. The maximum joint width is generally 25 mm; however, some products may be applied up to 50 mm in width. The minimum joint width is 6 mm; therefore, smaller cracks have to be routed to comply with this limitation. The minimum joint depth is generally about 6 mm, and the maximum depth is about 12 mm. These sealants are available in single and two components.

Single-component products are ready to use and do not require mixing; however, the color selection may be limited, and sufficient humidity must be present for proper curing.

Two-component products should be thoroughly mixed before using; they may cure faster in cold environments, and there is greater diversity in color choices.

Polyurethane sealants come in a variety of consistencies and hardness, making them suitable for vertical and overhead applications.

*5.2.1.2 Silicone Sealant*

Silicone sealants (Fig. 7) are generally used to seal cracks that are from 2.5 to 50 mm in width. Silicone sealants contain silicone polymers, fumed silica, plasticizers, calcium carbonate fillers, and silanes for adhesion. Most silicone sealants are packaged as a single component; however, they are also available in two component systems.

**Fig. 7:** Silicone sealant between frame and masonary

Sealant performance life typically is 3 to 10 years. Silicone sealants are highly resistant to UV light, and do not chalk or change color even when exposed for long periods of time. Silicone sealants have high elongation properties (500% and greater), making them suitable for active joints. Silicone sealants are not suitable for structural repairs. The adhesion to concrete and masonry is suspect unless a primer is used. Silicone sealants are not recommended for immersion; thus, they are not used for sealing joints within water tanks, reservoirs, dams, and the like. Silicone sealants behave poorly with respect to stress relaxation.

For optimum performance, silicone sealants should have regular inspections and maintenance.

As in the case of polyurethanes, joint design is critical to ensure that the sealant material behaves properly. A 2:1 joint width-depth ratio should be maintained. Joint widths should range from 6 to 25 mm, and depths should range from 6 to 12 mm. Therefore, smaller cracks will have to be routed to comply with this limitation. Silicone sealants are suitable for vertical and overhead applications. Some manufacturers offer sealant formulations that are suitable for traffic. When applied horizontally, they should be recessed and protected from traffic loads.

#### 5.2.3 *Polymer Impregnation*

Polymers can be used to impregnate conventional concrete after hardening, filling fine cracks, pores and voids. Very low viscosity resins, such as acrylics, can be applied, allowing them to soak in, or full impregnation can be achieved by pressure/vacuum. The method appears to work well for reducing surface permeability but where significant cracking is present there is the risk that if cracks are not sealed they can absorb water which subsequently becomes trapped. Pressure methods are used mainly for precast products when large increases in strength can be achieved. There is a high risk associated with use of acrylic resins, especially on site, due to their flammability.

#### *5.2.4 Overlays and Surface Treatments*

Most cracks in slabs are subject to movement caused by variations in loading, temperature, and moisture. These cracks will reflect through any bonded overlay, defeating the purpose so far as crack repair is concerned. Un-bonded overlays can be used to cover slabs with moving cracks. In highway bridge applications a minimum overlay thickness of 40 mm has been used successfully. Prior to overlay application, the surface should be cleaned to remove laitance, carbonation, or contaminants such as grease or oil. A bond coat of broomed latex mortar or an epoxy adhesive should be applied immediately before placing the overlay. Since latex mixtures normally solidify rapidly, continuous batching mixing equipment is needed.

## 6.0 Materials for Structural Crack Repair

The structural crack repair has to be made for structural strengthening of the member or to have the integrity of the structure. The various materials and methods are:

### 6.1 Polymer Modified Mortar/Concrete

These are based on concrete/mortar mixes and contain an emulsified thermoplastic polymer, such as styrene-butadiene rubber (SBR). They have a good film forming character, good water resistance properties. Other polymers, such as styrene acryl ate and PVA, may also be used, though the latter are not so good in wet conditions. Proportions of polymer in the region of 15 per cent by weight of cement are typical, though since emulsions are about 50 per cent water, the proportion of emulsion would be about twice this figure. A major advantage of polymer modified concretes is that curing times are greatly reduced, 24 hours usually being sufficient — by this time the material is completely waterproof.

Some are claimed to interact chemically with the cement. Permeability is reduced and flexural and impact strength is improved, partly on account of plasticising action, allowing reduced water content. A further advantage of these composites is that of adhesion to other materials, especially smooth surfaces; the bond is better than either the concrete or polymer individually. Many applications are based on this property combined with impermeability. They are used in concrete repair, thin concrete toppings on roads and pavements. Most varieties are marketed as liquids but emulsions can be converted into powders by spray drying which may have advantages in certain applications.

### 6.2 Polymer Cement Concrete

This description is given to concretes in which both polymer and cement contribute to binding action. The material hardens rapidly to give high compressive strength and high tensile strength, characteristic of the resin binder, though creep tends to be a problem. A variety of resins can be used and a polyester resin/cement mixture is available as a powder which is activated simply by adding water. Polymer cement concretes/mortars are expensive on account of their high resin content but are used where their rapid hardening, together with improved strength, toughness and durability justify this extra cost. Applications include thin floor toppings, concreting onto metal substrates, high speed repairs of pot holes and runways and bedding mortars.

### 6.3 Polymer or Resin Concrete

In this material, Portland cement is completely replaced by resin which, therefore, acts as the lubricant in the fresh material and the binder in the hardened material. The chief problem of such concretes is cost, since the resins, polyester, acrylic or epoxy, may cost quite high.

The fire hazard associated with acrylic resins should be emphasized; monomers may have flash point temperatures as low as 10°C. At low resin contents, both properties fall off sharply due to incomplete compaction, while at high resin contents performance is reduced as the low stiffness resin has to act increasingly as filler rather than an adhesive. The optimum resin content depends on aggregate characteristics. Comparative properties of 3 different types of resin are given in Table 2.

**Table 2.** Comparative properties of epoxy, polyester and acrylic resins for resin concrete

| Resin type | Viscosity | Shrinkage | Rate of strength development | Cost |
|---|---|---|---|---|
| Epoxy | Medium | Low | Low/Med | High |
| Polyester | Medium | Med/High | High | Medium |
| Acrylic | Low/Med | Medium | Medium | Med/High |

With a 20 mm well graded aggregate and intensive compaction, a resin content of about 6 per cent gives highest strength and this would result in an epoxy concrete with a high cost. If a more workable concrete or smaller aggregate were employed, the resin content would increase, being typically 15 per cent by weight for a patching mortar. The cost would, therefore, increase proportionately, although polymer concretes/mortars can achieve performance quite unobtainable using any other binder and are only normally required in small quantities.

Particular advantages include high tensile strength, abrasion resistance, impermeability and durability. There are many uses for resin mortars in repair works. They can be combined with fibres to produce a buttery consistency for use a bedding mortars in a wide range of applications, such as bonding of steel plates for strengthening structures (in conjunction with mechanical fixings).

## 7.0 Properties of Structural Repair Material

Based on the performance requirements the relative importance of structural repair material properties are given orderly as follows:

- Drying shrinkage: Since most repairs are made on older structures where the concrete will exhibit minimal, if any, additional drying shrinkage, the repair material must also be essentially shrinkage-free or be able to shrink without losing bond. The shrinkage cracking at 7 days should pass Coutinho ring test and shrinkage at 28 days should be less than 0.015%.
- Tensile Strength: Since concrete is weak in tension the tensile strength should be similar to that of original concrete substrate to avoid any failure and should be always more than the bond strength of the repair material. The tensile strength at 7 days should be minimum 2 MPa.
- Modulus of elasticity: The modulus of elasticity of a repair material should be similar to that of the concrete substrate to achieve uniform load transfer across the repaired section. The modulus of elasticity at 28 days should between 15-25 kN/mm$^2$.
- Adhesion/bond: In most cases, good bond between the repair material and the existing concrete substrate is a primary requirement for a successful repair. Bond is best specified as a surface preparation requirement. The minimum bond strength should be 1.0 MPa at 7days.
- Coefficient of thermal expansion: The thermal compatibility is most important in environments that are frequently subject to large temperature changes, it should also be considered in environments in which temperature changes are not as frequent.
- Creep: In structural repairs, creep of the repair material should be similar to that of the concrete substrate, whereas in protective repairs higher creep can be an advantage.
- Compressive strength: The repair material should have a compressive strength similar or slightly higher to that of the existing concrete substrate. But excessive compressive strength of new repair surface may cause reversal of stresses. The compressive strength at 28 days should between 30-60 MPa.
- Permeability: Materials with low water absorption and high water vapor transmission characteristics are desirable for most repairs.
- Besides above mechanical & compatibility properties the following parameters should be looked into during selection of repair materials such as workability, alkaline character i.e the chemical constituents of repair mortar should not adversely affect the alkalinity of base concrete, aesthetics to match the surrounding, cost, durable, non-degradable or non-biodegradable due to various forms of energy, life, UV rays heat etc. and non-hazardous/non-pollutant.

## 8.0 Conclusion

The performance characteristics for every repair method, separately for all intended uses and for certain intended uses should be mentioned in every repair project. The designer selects the performance characteristics based on the requirements of the special repair project and the selected repair methods. The characteristics relevant for the selected repair methods should match the performance requirement of the repair materials.

Prior to proceeding with the repair, a preconstruction meeting is recommended. The meeting should include representatives from participating parties (owner, engineer, contractor, materials manufacturer), and specifically address the parameters, means, methods, and materials necessary to achieve the repair objectives.

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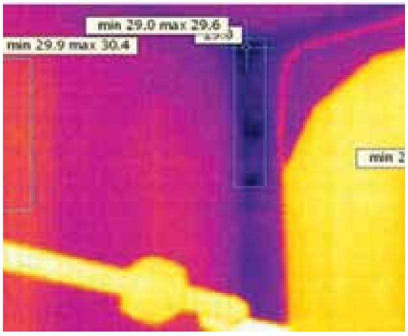


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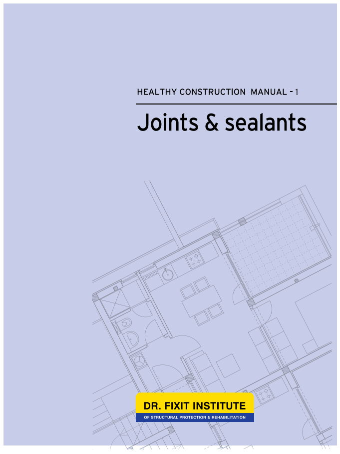


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