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 Fixit Guide to Healthy Construction, Cracks & Crack Repair (Unpublished)]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)	$25\text{-}30 \times 10^{-6}$	$10\text{-}20 \times 10^{-6}$	10×10^{-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.

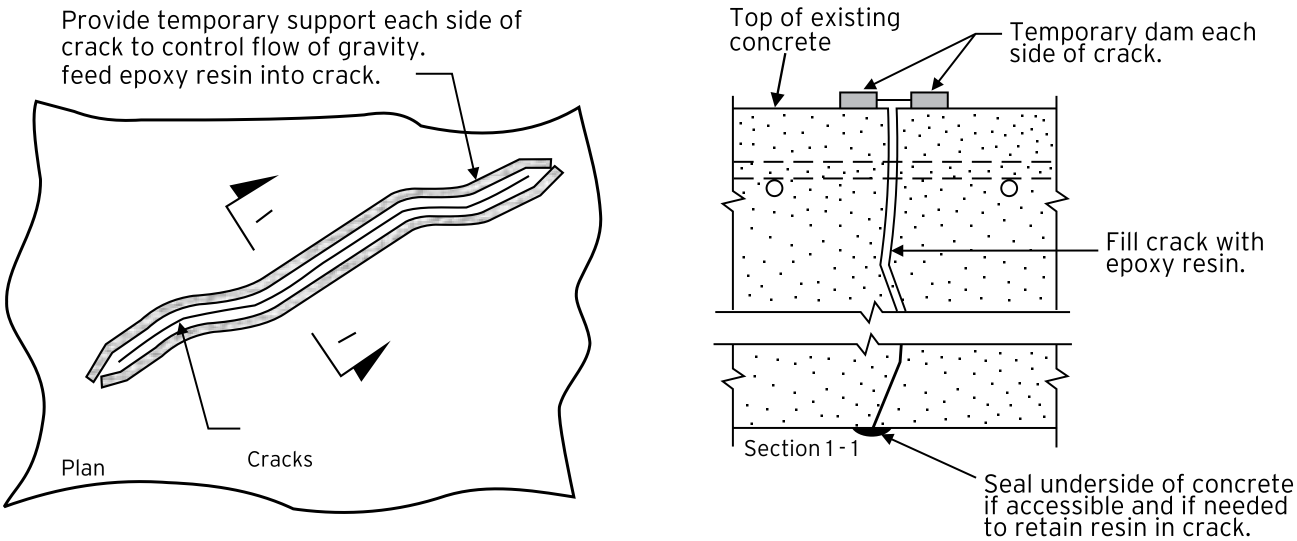

Fig. 4: Horizontal surface crack repair detail

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.

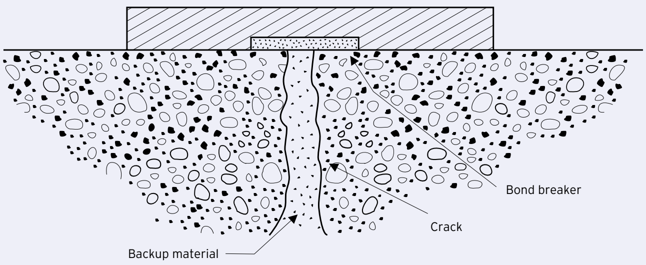

Fig. 5: Flexible sealing

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.