Selection and use of polymer-based materials in the repair of concrete structures

Kosednar, J.; Mailvaganam, N. P.

Publisher's version / Version de l'éditeur:
https://doi.org/10.1061/(ASCE)0887-3828(2005)19:3(229)
Journal of Performance of Constructed Facilities, 19, August 3, pp. 229-233, 2005-08-01

Selection and use of polymer-based materials in the repair of concrete structures

Kosednar, J.; Mailvaganam, N.P.

NRCC-47633

A version of this document is published in / Une version de ce document se trouve dans :
Journal of Performance of Constructed Facilities, v. 19, no. 3, Aug. 2005, pp. 229-233
Doi: 10.1061/(ASCE)0887-3828(2005)19:3(229)

SELECTION AND USE OF POLYMER-BASED MATERIALS IN THE REPAIR OF CONCRETE STRUCTURES

John Kosednar* and Noel P. Mailvaganam**

ABSTRACT

A large number of specialty repair concrete products are currently marketed and new products are being continually introduced leaving clients, engineers and designers bewildered. The paucity of information on the mechanical and thermal properties of a given product complicates material selection. These difficulties force designers to adopt materials that have properties close to those of the original concrete. In so doing they often reject advantages offered by polymer-based products now on the market. The challenge is to understand the properties of each material and select the appropriate one. To assure predictable performance, the designer must have a good knowledge and understanding of the properties of the repair material, how it will interact with the environment in-service, and a clear description of maintenance procedures and intervals. . Typical properties of currently used polymeric materials in relation to the important aspect of selection based on compatibility with in-service conditions and suitability with the application procedures of the job are discussed.

Keywords: Repair, Concrete structures, Polymer-based materials, selection, and compatibility

* Project Principal, Halsall Associates Ltd

2300 Yonge Street, Toronto, ON.

Canada, M4P 1E4

** Principal Scientist, Institute for Research in Construction

National Research Council of Canada, Ottawa, ON

Canada, K1A 0R6

THE SELECTION AND USE OF POLYMER-BASED MATERIALS IN THE REPAIR OF CONCRETE STRUCTURES

John Kosednar and Noel P. Mailvaganam

INTRODUCTION:

In virtually all concrete repairs one has the choice of using the original, conventional materials, or, incorporating products of a different type frequently polymer-based materials. Polymer-based materials are formulated to provide properties tailored to the requirement of a specific application and take into account wet-state properties, surface penetration and wetting ability and hardened properties such as strength and permeability. Design engineers however, are more interested in the final hardened state properties — flexural strength, elastic modulus, shrinkage and creep. They will also want to know the changes in properties with time and how the various properties are affected by changes in temperature and humidity. Product manufacturers rarely have such an array of information. Information relating to the important aspect of selection of polymeric materials based on compatibility with in-service conditions and suitability with the application procedures of the job is presented. Typical properties of the materials currently used are detailed and their advantages and limitations for use in a given set of conditions/environment are described.

MATERIAL SELECTION AND SPECIFICATION:

The selection of repair materials is a predictive effort to maximize future performance or durability. Therefore, selection must be based on the knowledge of the physical and chemical properties, the function the designer plans to impose on them and the nature of the environment in which they will be placed. Almost every repair job has unique conditions and special requirements. Once these criteria are known, it will often be found that more than one material can be used with equally good results. Final selection of the material or combination of materials must then take into account the ease of application, cost, available labor skills and equipment. Mailvaganam N. and Alexander. A (1996)

Selection Criteria

For polymer-based materials,— where the binding matrix is a polymeric resin— or polymer modified repair materials,— consisting of a cementitious matrix containing latex— performance criteria are much less well established than is the case for traditional materials such as concrete, brick and steel. The engineer therefore lacks the familiar starting point from which to make his materials selection. When selecting any polymeric materials for repair applications, certain key points must be appreciated:

(1) Their physical properties are uniquely different to traditional construction materials i.e., there is a basic ‘mismatch’;

(2) Service conditions usually affect a bonded composite, not an isolated polymer;

(3) Organic polymers represent an extremely broad class of chemical and physical types. Combined organic/inorganic systems widen the range still further;

(4) Polymer properties are sensitive to relatively small temperature changes and they are significantly time dependent;

(5) Ultimate properties can be markedly affected by the ambient conditions during application;

(6) Polymer behavior is significantly affected in some applications by the behavior of the substrate, particularly how it responds to load.

Plum. D (1991), ACI SP-21(1968), Kuhlman. L. and Walters, G. (1993), Mailvaganam N. and Alexander. A (1996)

Material properties

Durable repairs can only be obtained by matching the properties of the base concrete with those of the repair material intended for use. Some of the material properties that should be considered when selecting a compatible repair material include (1) dimensional stability (2) coefficient of thermal expansion (3) modulus of elasticity (4) permeability (5) chemical compatibility and (6) electrical properties. Plum.D. (1991) Hewlet. P. and Hurley S.A. (1986), Alfred R., Alfred H., and Gustave P., 1984.

1. Dimensional stability

The provision of a good bond between the polymer-based repair material (e.g. a patch) and the concrete substrate is an important requirement for restoring monolithic character. Since most repairs are performed on older concretes which have negligible shrinkage, the repair material must possess very low shrinkage or else be able to shrink without losing bond. Cusson. D. and Mailvaganam. N (1996), Kuhlman. L. and Walters, G. (1993),

2. Coefficient of thermal expansion

When making large or thick patches or when placing an overlay, it is important to closely match the coefficient of thermal expansion of the repair material with the concrete being repaired. The differences in volume change that arise when a composite of two materials with quite different thermal coefficients undergo a significant temperature change, often causes failure at the bond interface or within the section of lower strength material**.** J.Warner (1984). This is best exemplified in the failure of repaired cold room floors. Deteriorated cold floors are often repaired with epoxy toppings, the thermal coefficients of which are five times that of the concrete substrate. Thus, unless the basic epoxy resin used in the formulation has the capability to relieve stress by its elongation capacity, delamination of floor toppings will occur by shearing off in the region just below the bond interface as the in-service cold temperatures are reintroduced. (Table 1).Ohama.Y. (1996) Hewlet. P. and Hurley S.A. (1986).

3. Modulus of elasticity

Low modulus materials like polymer-based repair products deform more under load than high modulus materials. When materials with widely different moduli are in contact with each other, the significant difference in deformability will cause problems under specific loading conditions. For example, Figure.1 (a).shows that when load is perpendicular to the bond line the difference in modulus does not cause problems. However, when the load is applied parallel to the bond line, as in Figure.1 (b). deformation of the lower modulus material transfers load to the higher modulus material that may then fracture. This type of problem can occur at the edge of a patch and is particularly likely to happen when dynamic (impact or vibration) forces are present. This was clearly observed in the failure of a repair done on a load on/load off dock . A 50 x254 mm (2"x10") spall was repaired with a 203.2x 304.8 (8"x12") patch of epoxy mortar. The rationale was that the epoxy mortar provided good adhesion to the existing concrete and would be able to better absorb the impact stresses imposed during the off loading of heavy material from barges. The impact stresses from the off-loading however, were transferred to the concrete substrate (as in Figure.1. b), and a more drastic spalling —in which 787.4 mm (31”) of the concrete substrate was pried loose — occurred within a year.

Not all failures related to interfaced materials with widely differing modulus of elasticity materials are caused by external loads; shrinkage or thermal expansion and contraction can also cause loss of bond and subsequent delamination. This is less likely to happen if the modulus of the repair material is low enough to permit movement without excessive stress at the bond line. Sasse. H.R. (1986), Cusson. D. and Mailvaganam. N (1996),

4. Permeability and Chemical compatibility

Polymer-based concrete patches are often used in the repair of extensive areas of the concrete surface, particularly in situations where the service conditions involve exposure to aggressive chemicals. If impermeable polymer materials are used for large patches, overlays, or coatings, moisture vapor that passes up through the base concrete can be entrapped between the concrete and the surfacing. Entrapped moisture can saturate the surface layers causing failure by freeze-thaw action either at the bond line or within the weaker of the two materials. This type of failure is often observed in parking garage decks coated with elastomeric polymeric waterproofing membranes.

The reactivity of the patching material to steel reinforcing and other embedded metals surrounding concrete or specific protective coatings or sealers applied over the patch must also be considered. Patching materials with moderate to low pH may provide little protection to reinforcement. Moreover, certain patching materials are not compatible with waterproofing membranes required as protection following repair. Therefore, reactivity of the various patching materials with both the substrate and surface protection product should be checked. Mailvaganam N. and Alexander. A (1996).

5. Electrical properties

The resistivity of the patching material may also affect the durability of the patch and the concrete in the member undergoing repair. Materials that are highly resistive or nonconductive have a tendency to isolate the repaired area from adjacent undamaged areas. Consequently, if there is a large permeability or chloride content differential between the patched area and the rest of the concrete, the corrosion current becomes concentrated in a restricted area and the adjoining concrete. (Fig.2.) Revie, R.W. Ed (2000). The consequences of this electrochemical incompatibility between the newly installed patch and the adjacent, existing concrete is the chief cause for the delamination and hence failure of such patches. Cusson. D. and Mailvaganam. N (1996), Schupack.M. (1980)

Clearly considerations for selection therefore, will involve a knowledge of the repair dimensions, in conjunction with a variety properties of both the repair material and concrete substrate and a review of the test methods used to obtain the published product data. In addition, the choice of the right product also depends on the anticipated service conditions and the prevailing conditions at the time of application of the products.

Application Parameters

An organized approach to material selection helps to rationalize the many chemical and physical variables and many material choices for the intended job conditions. The necessary steps are as follows: Mailvaganam. N. (1992), Plum.D. (1991), Sasse. H.R. (1986)

1. Definition of service conditions; in-place load exposure- compressive, tensile and shear loads; in-place environmental exposure, weather, chemicals, de-icing salts and abrasion.
2. Determination of required installation parameters patch geometry; thickness, shape and depth; coating and membrane thickness and application properties and placement method; hand applied, form and pour, form and pump or spray applied.
3. Equipment required.
4 Factoring in the practical constraints; accessibility, down time, and keeping the facility open while work is done.

5. Considering the interaction of the material with the substrates; bond, strength gain with time, shrinkage and resistance to cracking during curing.
6. Testing of the most likely materials.

Many coatings, membranes and adhesives have special application requirements that are peculiar to their systems. Different ingredients influence not only application techniques, but also determine substrate requirements (e.g., a smooth surface for thin coatings and a more bodied material for a textured surface). A checklist of important application properties should include: Plum.D, ACI S.P. 21 (1968), Y Ohama. (1996)

- Viscosity - should it be high or low?
- Flow characteristics - should the material be suitable for brushing, roller coating, spraying, or trowelling? Is it to be applied on vertical or horizontal surfaces?
- Pot life - must it be unusually long or short?
- Curing - what limits—primarily moisture and temperature — are acceptable under the prevailing application conditions ?
- Continuity of paint film - is a continuous film readily attainable on a concrete surface?
- Coverage per coat - what film thickness is necessary and what coverage in square feet per gallon) or square meters per liter) does this represent?

The common problem of the delamination of elastomeric membranes —applied over the concrete decks to prevent the ingress of moisture and chlorides— in parking garages occurs when one or more of these application properties is overlooked.

Test Methods

The existence of a very broad range of formulations and product types, together with the complex nature of polymers, and the variations in the in-situ conditions and type of application complicates the selection based on the current methods used to evaluate these materials. Temperature and the rate of load application more significantly affect their physical properties. For example, the ‘ultimate strength’ of a polymeric material, as normally quoted by manufacturers, is conventionally obtained by a destructive stress over a relatively short period (typically one to two minutes). However, if a constant stress is applied for a much longer duration (days) failure can occur at much lower (perhaps <50%) of the short-term strength. Hewlet. P.C. (1993), Ohama. Y., (1996)

To measure the properties of such materials more meaningfully, it is therefore desirable to standardize specific procedures that take into account the above factors. The new ACI Guidelines and particularly the British Standard" Testing of Resin Compositions for Use in Construction", BS-6319.1983/84 provide information in this regard. It must be emphasized however, that testing according to standardized procedure does not guarantee suitability of a repair material for its intended application. Consequently, informed judgement is still required when selecting materials.

Specifications

Polymer-based repair materials can be innovative but may not conform to the usual conventions. In this respect codes and regulations do not necessarily bind the specification of repair materials and techniques. In the absence of code and regulations covering the application or repair materials the designer and specifier, in considering a product, must evaluate, critically the following: Plum.D. ACI S.P. 21 (1968), Y Ohama. (1996)

1. The product's field history under conditions similar to the job at hand, and whenever possible, long-standing examples of successful applications available for inspection.
2. The relevance of the test data in the product literature.
3. The products applied and the long-term maintenance cost.
4. Compatibility of the product with other materials that form the composite unit.
5. The good standing of the manufacturer, and the length and conditions of this guarantee.
6. Limitations of the product.

Job specifications that take into account the above items should then be developed to define the material or product type required and the quality of the installed system. Such a specification may include, but is not limited to, the following: Plum.D, (1991)ACI S.P. 21 (1968), Hewlet. P.C. (1993), Mailvaganam. N. (1992)

- Type of product and product parameters (such as thickness of coating) to suit service conditions.
- Stipulation that all technical data from the manufacturer be submitted to the specifying agency.
- Specifications on concrete quality and type of finish required for the application of other products such as membranes or coatings.
- Limitations and requirements during application that will be imposed by weather conditions such as temperature, rain, and winds.
- Stipulations of construction details (such as joints, drain) required for the installation of auxiliary products such as membranes and sealants.
- In the case of coatings and membranes, a stipulation that the applicator be approved and certified by the manufacturer to supply an unconditional 3 to 5 year guarantee for the performance of the material.

PROBLEMS IN THE USE OF POLYMER-BASED MATERIALS

Although most problems mainly originate from the relatively short history of using polymer based materials for repair, they are also compounded by the multitude of currently available products many of which appear to be similar but are, in fact subtly different. Even one class of polymers, thermosetting resins, includes a variety of systems.viz: epoxies, polyurethanes, polyesters, furanes, and acrylates, each of which may be formulated to give numerous individual products. Other classes of polymers such as thermoplastics, latex emulsions and elastomers extend the list further. In isolation many polymeric materials or polymer modified cementitious systems are very durable, even in aggressive conditions. Why then are there so many failures after relatively short time when these materials are used in situations where they are bonded to concrete?

A high proportion of the failures can be attributed to incorrect use or difficult site conditions. Proper use is certainly a prerequisite for satisfactory performance. Failures however, can often be attributed to a lack of clear recognition of fundamental differences between polymers and concrete, e.g., the relative strain, rather than the stress tolerance, of resins and concrete. Significant advances therefore, could be made by the designer and specifier in matching the repair product and concrete substrate to give a combination with acceptable durability. The inherent mismatch between the common materials of construction and polymer-based systems is illustrated by the properties given in Table 1. Y Ohama. (1996), Hewlet. P. and Hurley S.A. (1986).

Property mismatch and composite performance:

Whatever the specific application, the specifier, and designer must balance three main variables- (1) material properties ideally required (2) relevance of the supporting test data and (3) properties which are likely to be realized and maintained under site conditions - in the pursuit of durability of the repair. This requires an understanding of the basic nature of the repair materials and also the test methods used in obtaining the stated properties. Hewlet. P. and Hurley S.A. (1986).

In virtually all repairs, good adhesion is a prime requirement. This intimate contact of physically different materials dictates that a knowledge of individual properties, although essential, will be insufficient for proper selection. All too frequently, only the isolated mechanical properties of polymer compounds are emphasized, whereas more important properties of the composite are neglected. Some of the critical parameters that should be considered in trying to establish compatibility between the polymer and concrete in a composite system are (a) the range of polymer properties even within a specific class of polymers (b) the marked temperature/time relationship in polymers and (c) the effects of cure conditions. Hewlet. P. C.(1993)

(a) Range of Polymer Properties:

The broad spectrum of polymer properties can complicate the matching of properties in the repair unit (composite) and hence selection. For example, although simulated field-testing can be informative; unfortunately, it can be misleading to extrapolate results from one formulation to another, even for the same class of material. It is important therefore; to characterize materials completely as possible and wherever possible obtain more details of the compositions tested. Hewlet. P. and Hurley S.A. (1986).

(b) Temperature/Time relationship

Unlike concrete, the physical properties of polymers are markedly affected by small temperature changes and the mechanical properties are more time dependent. For example, a 20-30^{0}C variation in temperature may transform a material that is hard and strong at 20^{0}C to one which is hard but brittle at 0^{0}C, or very much softer and weaker at 50^{0}C. Most polymers are viscoelastic, displaying a delayed elastic response which becomes more pronounced at higher temperatures. Consequently, creep is more marked than in the case of concrete. Fortunately, many repair applications that use polymer-based products are, at most, semi-structural and this effect can be ignored. However, it highlights the need for more consideration where structural uses impose a high stress on the polymer and its bond to the substrate.

While this marked time temperature dependence is undesirable in structural repairs (due to excessive creep strain) it must be pointed out that viscoelasticity can be beneficial. The stress relaxation from creep strain may allow potentially destructive stresses to dissipate. Such relief may occur, e.g., in screeds, patching mortars, and nosings, where stresses arise from cure and exotherms, shrinkage and, also from temperature recycling during service. ACI. S.P. –21 (1968)

(c) Curing Conditions:

The final product is a consequence not only of the specific chemical composition chosen, but also of the care taken in application and the condition under which the cure reaction takes place. There is often less appreciation of how factors such as (i) initial temperature of the material, (ii) temperature and humidity during cure, and (iii) mass of the system affect the performance of thermosetting resins. Some examples that show the effect of such factors are: Y Ohama. (1996)

(a) Severe retardation of some epoxies systems stored in trucks at 0-5^{0}C.
(b) Adverse effects of low initial temperatures on the handling characteristics and surface wetting properties of resins due to marked increase in viscosity—encountered in the installation of elastomeric membranes in late fall
(c) The effect of the prevailing temperature and humidity on cure rate of one-pack polyurethanes and water dispersed epoxies and neoprenes, installed in late fall

CONCLUSION

Perhaps the major factor that has been responsible for the extensive use of polymer-based materials in civil engineering is their versatility. They can be`tailored' by the chemist/formulator for a wide variety of applications. However, this very versatility demands that the designer, specifier, and user first acknowledge the likelihood of polymer-concrete mismatch and secondly, exercise a clear means of judging materials at the selection stage.

Specifiers and user should satisfy themselves about such properties as coefficient of thermal expansion, cure/temperature/time response, shrinkage, modulus, and creep. Manufacturers' data should include information on the glass transition temperature and relate to prevailing cure and service temperature conditions so that engineers can use this information to predict polymer response to temperature change as expected in service.

The lack of widely agreed upon methods of assessment leaves repair materials subject to narrow and limited evaluation driven more by manufacturers rather than users. Since repair materials and techniques are being actively developed, compliance with standardization methods is inappropriate for any thing other than single property/comparative testing of the various types.

References

1. Alfred R., Alfred H., and Gustave P., 1984, "Experiences on Barrier Layer on the Surface of Concrete." *Proceedings of the RILEM Seminar on Durability of Concrete Structures under Normal Outdoor Exposure* March 26-29. Hanover, Germany pp., 116-125.

2. Cusson, D., & Mailvaganam, N. P., March 1996, " Durability of Repair Materials" *Concrete International*, The magazine of the American Concrete Institute Volume 26 N0: 9 pp 35-38.

3. *ACI Publication S.P. 21,* - 1968. "Epoxies with Concrete." ACI, Detroit, Michigan. Pp., 5-8, 29-36 and 93-106.

4. Hewlet, P. C., & Hurley, S.A., 1984, " The Consequences of Polymer-concrete Mismatch" *Proceedings, The Design Life of Buildings, Joint Institute of Civil Engineers/Concrete Society/RIBA Symposium.* pp 26-27, 179-196. Thomas Telford.

5. Hewlet, P. C., March 1993, " Assessment &Evaluation of Polymer-Based Repair Materials" *Concrete International*, The magazine of the American Concrete Institute Volume 22 N0: 3 pp 35-38.and 39-41.

6. Kuhlmann l., & Walters G., 1993, ed. "Polymer Modified Hydraulic - Cement Mixtures." *STP 1176, ASTM* Baltimore pp., 7-18, and 35-43.

7. Mailvaganam N.P., 1992, ed. Repair and Protection of Concrete Structures, Chapter 1 The Science of Concrete and Polymeric Building Materials. pp 31-42. CRC Press, Florida, USA.

8. Mailvaganam, N. P., & Alexander, A., 1996, "Selection of Repair Materials Using Expert Advice" *Concrete Repair Bulletin*, Jan/Feb, Volume 12. No: 3 pp 12-15. Baltimore USA

9. Ohama, Y., 1996, " Polymer-Based Materials for Repair and Improved Durability: Japanese Experience" Special Issue on Investigation and Repair of Concrete Structures, ed. N.P. Mailvaganam P., Mailvaganam, Journal *of Construction and Building Materials* Vol 10, No 1, pp 77-82. Edinburgh, U.K.

10. Plum D., 1991, "Materials - What to Specify?" *Journal of Construction, Maintenance & Repair,* July/August Volume 6, No, 2 pp., 3-7 Sheffield U.K.

11. Sasse H.R., 1986 ed., "Adhesion between Polymers and Concrete. *Proceedings, RILEM International Symposium, Paris, September 16-19*, pp., 144-151 and 230-244.

12. Schupack, M., Oct 1980 "Divorces and Ruptured Relations Between Epoxies and Concrete" *Journal of Concrete Construction,* Addison ILL, USA pp 735-738

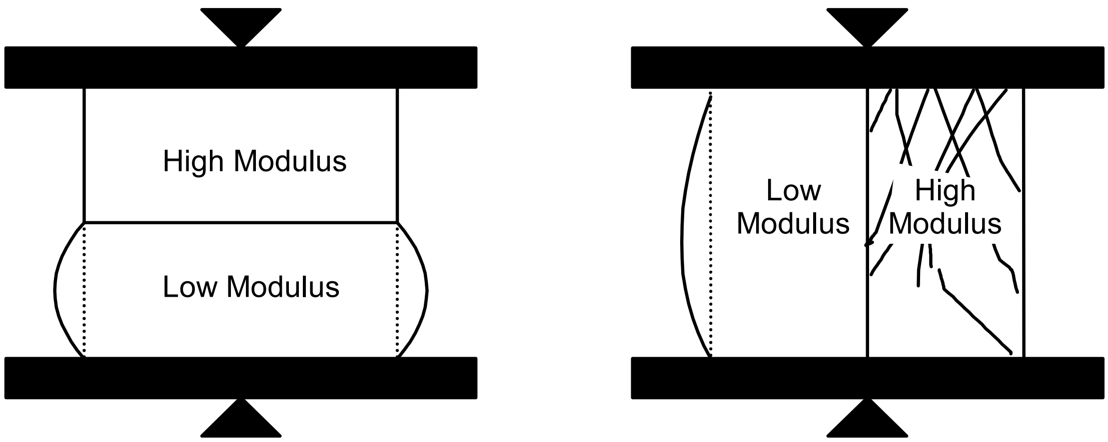
13. Warner, J**.**, October 1984. Selection of Repair Materials, *Journal of Concrete Construction,* Addison ILL, USA pp 72-74.

14. Revie, R.W. Ed (2000) "Corrosion of Steel in Concrete" *Uhlig's Corrosion Handbook, 2nd edition* Interscience New York pp-581-600.

LIST OF TABLES AND FIGURES

TABLE 1 TYPICAL PROPERTIES OF ORGANIC POLYMER GROUTS
{Reference.9.with permission]

Property/Test Method	Epoxy Grouts	Polyester Vinyl Esters
Tensile Strength ASTM 37-61 (modified)	1,000–3,000 psi (10-20 MPa)	2,400 psi (16.5 MPa)
Compressive Strength ASTM C579-75, Method B	10,000–15,000 psi (69–1031 MPa)	14,000 psi (96.6MPa)
Flexural Strength ASTM C550	3,000–5,000 psi (21–34 MPa)	4,250 psi (29 MPa)
Flexural Modulus of Elasticity	12–20 MPa	12.4 MPa
Bond Strength to Steel	1,500–3,000 psi (10–20 MPa)	2,400 psi (16.5 MPa)
Density or Specific Gravity	125–140 lbs/cu.ft (2–2.4 g/cm^3)	212 lbs/cu.ft (3.4 g/cm^3)
Linear Unrestrained Shrinkage ASTM D.2566	0.001–0.002 in/in 0.001–0.002 cm/cm	0.04 in/in 0.04 cm/cm
Coefficient of Thermal Expansion ASTM C-531-68	15–30 x 10^{-6} (in/in/°F) 27–54 x 10^{-6} (cm/cm/°C)	15.3 x10^{-6} (in/in/°F) 27.5 x 10^{-6} (cm/cm/°C)
Bond to Concrete	Stronger than concrete	Stronger than concrete
Impact Strength	Better than concrete	Better than concrete
Abrasion Resistance	Better than concrete	Better than concrete
Cure Time to reach 10,000 psi / 69 MPa		
Compressive Strength:		
90°F/ 32.2 ^{0C}	18 hours	16 hours
70°F/ 21.00^{0C}	42 hours	24 hours
50°F/ 10.00^{0} C	28 days	36 hours



(a) Load perpendicular to the interface **(b) Load parallel to the interface**

Fig. 1: Effects of Mismatching Elastic Moduli
(From [13] with permission)

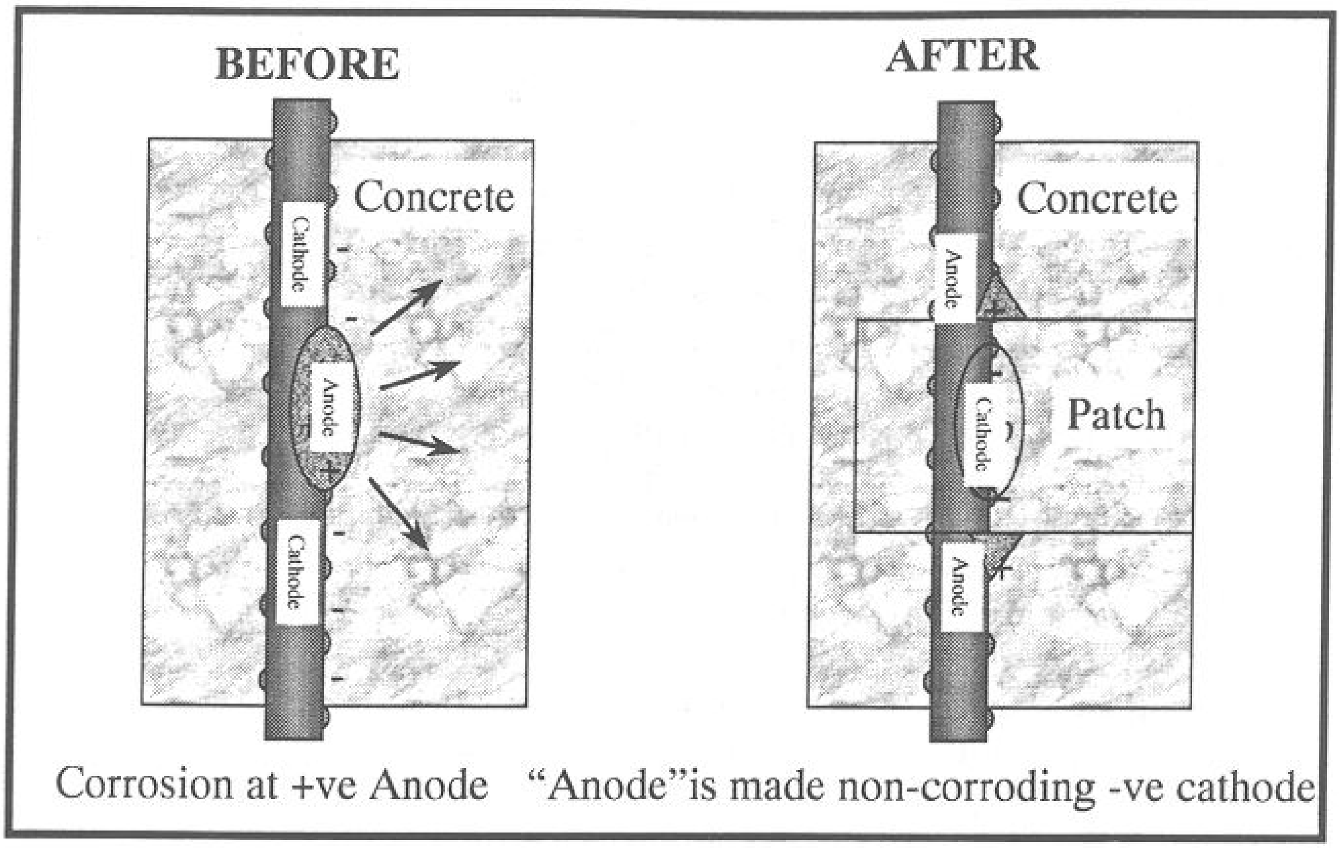


Fig. 2 Formation of anodes on either side of the patch due electrochemical incompatibility (Broomfield—Uhlig's corrosion book handbook .Ref.14)