A review of resins used in construction

Types of resin — applications — case histories

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The various ways in which resins can be used in structural applications are reviewed. Epoxy resin and polyester resins systems are described and compared for each application. Their use in adhesives, grouts, and mortars for both construction and repair work is compared with conventional materials, indicating where they can be used to advantage — always with the proviso that they are correctly formulated and applied.

Key words: epoxy resins; polyesters; concrete structures.

The use of resin systems in civil engineering applications has been established for over quarter of a century. Resins are now being used extensively, mainly in repair applications but also, to a limited but growing extent, in structural design concepts and in other less critical applications where the use if high performance resin materials have proved more cost effective than traditional construction materials in view of time and/or labour saving. The resins referred to are principally epoxy resin systems and unsaturated polyester resin systems which have been specifically formulated for use in the construction industry. Polyurethane resin systems have also found use particularly in the field of chemically resistant coatings and flooring applications.

Epoxy resins were first developed in the early 1940's. Initially they were investigated for applications in dentistry which, to date, have not proved to be viable. However, it was realized that epoxy resins could be formulated to produce high strength materials with excellent adhesion, resistance to a wide range of chemicals and good electrical insulation properties[1]. Development over the past 30 years has established a very wide range of applications for epoxy resins from highly critical structural adhesives in aircraft construction, adhesives for domestic applications, carbon fibre reinforced golf clubshafts, chemically resistant lacquers used to line virtually every food and beverage can produced, encapsulation resins for both heavy electrical and microprocessing uses, to specialist adhesives, mortars, grouts, *etc* for the construction industry.

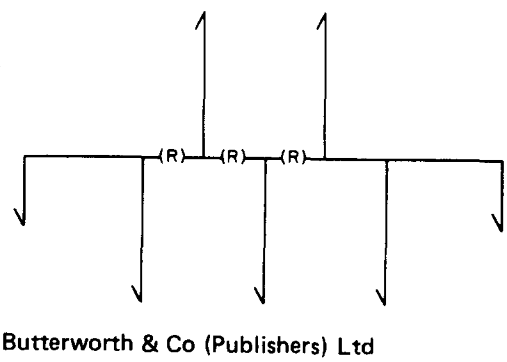
Unsaturated polyester resins were discovered in the mid 1930's and were initially used in the formulation of lacquers particularly for wood finishing and then for low pressure laminating resins. Glass fibre-reinforced polyesters have now developed into a major industry, particularly in the construction of boats, from small sailing dinghies to anti-magnetic minesweepers, and for specialist car bodies, chemically-resistant storage tanks, *etc*. The unsaturated polyester resins used in civil engineering applications are directly derived from the resins used in boat construction, but in the UK normally employ modified curing systems which are more reliable under typical building site conditions (cold and damp) than the systems used under factory production conditions.

Resin systems

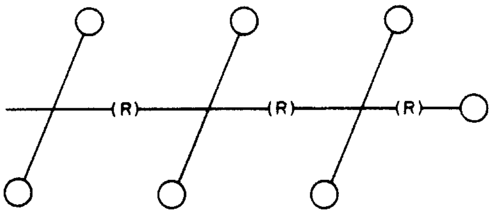
Both epoxy and polyester resins are classed as thermosetting materials because, when cured, the molecular chains are locked permanently together and, unlike thermoplastics, do not melt or flow when heated but become more rubbery and lose strength with increase in temperature. They are generally supplied as two- (or even three-) component systems. The chemistry of the two resins is, however, significantly different.

Epoxy resins

Epoxy resins consist of a reactive resin which can, in non-chemist terms, be considered diagrammatically (much simplified) as a material with reactive 'hooks':



and a hardener (or curing agent) with reactive 'eyes':



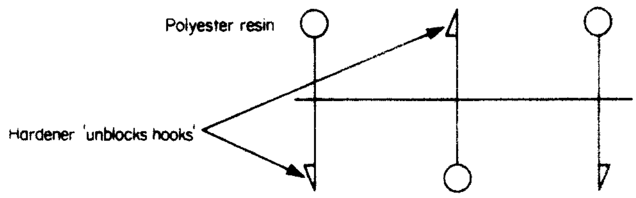
To achieve the full properties of the cured resin system the right number of 'hooks' must be intimately mixed with the right number of 'eyes' so that in the pot of mixed resin (*ie* three dimensionally) a hook is immediately adjacent to an eye.The properties required for a specific application are achieved by careful attention to the chemistry of both the resin and hardener which is influenced by the precise chemical nature of the groups (all denoted by (R) in the diagrams) between the chemical 'hooks and eyes'. The nature of these structures and also the nature of other additives in the formulation will influence the ultimate strengths, rate of cure at different temperatures, and also whether the formulation will bond under damp conditions (or even under water). Correct proportioning and thorough mixing is, therefore, imperative when using epoxy resin systems.

The curing (hooking up) of epoxy resin systems is an exothermic reaction and the rate of cure is temperature-dependent. In general terms, the rate of cure doubles as the temperature increases by 10°C and halves as the temperature drops by 10°C. Many formulations stop curing altogether as the temperature drops below about 5°C although there are available epoxy formulations which will cure down to approximately 0°C. In warm weather the exothermic heat developed during cure with epoxy resins can be excessive and give rise to problems: it is for this reason that alternative formulations are often necessary for winter curing conditions and also for tropical curing.

In the cure of epoxy resins, maximum heat evolution due to the reaction occurs whilst the resin is still in a fluid state, but, in some conditions the resin composition will set rigid whilst it is at a temperature significantly above the adjacent substrates. Thus, thermal contraction can occur, causing stresses to be built up at the interface between the resin composition and the substrates. The change in volume between the mixed uncured epoxy resin+hardener and the fully cured polymer is low and if carefully formulated, carefully mixed, and applied according to the formulator's instructions can often be considered to be negligible. However, for each application, the volume of epoxy resin to be placed, thickness, temperature of mixed resin system and cure temperature all need to be carefully considered to avoid shrinkage due to thermal contractions.

Polyester resins

Polyester resin systems are chemically much more simple in that the liquid resin component contains both the 'blocked hooks' and the 'eyes' in the right proportion intimately mixed together. The hardener (or catalyst) component, which is generally in the form of a fine filler, but can also be a low viscosity liquid or paste, is purely required to initiate the 'unblocking' of the hooks which once initiated is, to some extent, a chain reaction which continues throughout the mass of the polyester resin:



Mixing and proportioning of the hardener component is, therefore, less critical than for epoxy resin formulations although the cure at the interface between the polyester resin mass and the substrate may be inhibited under certain not-always-well-defined conditions, resulting in loss of adhesion.

Like the epoxy resin systems, the cure of polyester resin systems is also exothermic but, unfortunately, the maximum heat evolution occurs after the resin has set. This can result in significant thermal contraction inducing high stresses which build up at the interface between adjacent substrates and the polyester resin composition and can cause adhesive failure at these interfaces.

In addition to this possible thermal contraction of a polyester resin system there is also a change in volume between mixed uncured polyester resin system and the fully cured set polymer (curing shrinkage).

Because of these two factors, polyester resin formulations must, in general, be limited to application in relatively small areas at one time and most formulators do make recommendations on the maximum areas/thickness that can be applied for a particular polyester formulation at one time.

By careful formulation, polyester resin mortars have been developed which can be laid 6 mm thick on carefully prepared concrete substrates to produce heavy duty highly chemically resistant continuous flooring compositions[2].

Providing polyester resin systems are applied with strict adherence to the formulator's instructions they can prove extremely valuable materials to the civil engineering industry, particularly because of their extremely rapid development of strength in comparison with most other construction materials. 'Stronger than concrete in two hours' can justifiably be claimed. In fact, specifications from one major user of polyester bedding mortars require that the material must give a 40 N/mm^2 compressive strength within 2 hours at 4°C. Not surprisingly, a special winter grade is required for this contract, but polyester resin compositions with a useable life of 25-30 minutes at 20°C will develop compressive strengths in excess of 70 N/mm^2 within 24 hours at 0°C. Polyester resin compositions are available to repair floors in cold stores operating at minus 20°C.

Until recently, virtually all the polyester resins used in the construction industry were based on styrene monomer as an essential component; there are now available a number of very similar resins based on acrylic monomers which give results of similar technology but some acrylic (polyester) resin systems are available which exhibit less shrinkage than more conventional polyester resin systems and can be formulated to produce very low viscosity injection/impregnation systems.

In civil engineering applications, resins are almost invariably used directly bonded to concrete or other cementitious material. It is, therefore, important to compare the mechanical and other properties of resin systems with those of concrete – these are given in Table 1[3].

At present, there are no standard test methods for resin

Table 1. Physical properties – a comparison of typical products

	Grouts, mortars and concretes		
	Epoxy resin	Polyester resin	Cementitious
Compressive strength (N/mm^2)	55 – 110	55 – 110	20 – 70
Compressive modulus (E-value) (kN/mm^2)	0.5 – 20	2 – 10	20 – 30
Flexural strength (N/mm^2)	25 – 50	25 – 30	2 – 5
Tensile strength (N/mm^2)	9 – 20	8 – 17	1.5 – 3.5
Elongation at break (%)	0 – 15	0 – 2	0
Linear coefficient of thermal expansion, per °C ($\times 10^{-6}$)	25 – 30	25 – 30	7 – 12
Water absorption, 7 days at 25°C (%)	0 – 1	0.2 – 0.5	5 – 15
Maximum service temperature under load (°C)	40 – 80	50 – 70	> 300*
Rate of development of strength at 20°C	6 – 48 (hours)	2 – 6 (hours)	1 – 4 (weeks)

*Dependent upon design of mixture

compositions used in construction applications and, as a consequence, published mechanical properties may have been measured using a number of totally different test methods not always reflecting the actual conditions of use (specimen size, aspect ratio, methods of sample preparation *etc*). Happily this situation is currently being resolved and FeRFA (The Federation of Resin Formulators and Applicators) are working closely with BSI Technical Committee CSB/20 on the production of practical test methods[4].

It is important to note that both polyester and epoxy resin systems have a lower E-value (compressive modulus) than concrete and this has to be taken into account when designing resin/concrete structures. Another factor which can be most important is creep.

At the symposium: Resins and Concrete held at Newcastle University in 1973 there was some criticism of the resin formulating industry concerning the lack of creep data for most of the formulated products on the market. Much more information is now available on the creep of resin systems. However, it is the author's opinion that for most applications where resins are used in a critical structural mode, creep is far less of a problem than some design engineers tend to indicate. This is because the aspect ratios of most resin compositions in critical applications are very low. Although the creep characteristics of the epoxy resin adhesive system used successfully in the segmental construction of Rawcliffe Bridge (over the Dutch River near Goole, UK) in 1966 are inferior to those of systems currently being used for similar applications, testing carried out before the adhesive was specified indicated that this system had adequate creep resistance – this had been proven by 15 years, to date, in service without problems[5]. Resin formulators are, however, seeking to develop resin systems with the lowest creep possible, as this will give design engineers greater scope in the use of resin compositions in high performance design concepts.

Concrete substrate

Before considering the applications for which resin systems have been used extensively over the past 25 years, it is important to consider the nature of the substrate on to which the resin compositions are most commonly applied – *ie* concrete. In virtually all applications where resin compositions are used in conjunction with concrete, the composition is bonded to the surface of the concrete. The surface strength of the concrete in tension/shear plays a vital part in the performance of the resin/concrete composite. It is possible to have a concrete substrate which, on the basis of its cube strength, is very satisfactory but which has a low surface strength. This will give rise to problems in service if the concrete surface is not adequately prepared to provide a clean sound surface on to which the resin composition can be applied. Suitable surface preparation techniques are numerous; suffice to state that lack of adequate surface preparation has, in the experience of the author, been one of the main reasons for poor results when resin compositions have been used.

Applications for resins

Practical applications where the properties of epoxy and polyester resin compositions have been used to advantage in civil engineering can be summarized as: adhesives in a variety of different applications; structural mortars; heavy-duty grouts for the precision installation of machinery and crane rails; grouts and chemical fixings for bolts, starter bars *etc*; and concrete repair applications. These are discussed in more detail below.

Adhesives

Resin adhesives based on both epoxy and polyester resin compositions are used in many different applications in civil engineering. The bond and shear strengths of correctly formulated resin based adhesives are considerably greater than those of good quality concrete, so that in many instances damaged concrete structures can be restored to structural integrity by use of resin adhesive.

Bonding new to old concrete

One useful application for epoxy resin based adhesive is to achieve a good shear connection between new uncured concrete and old fully cured concrete; thus eliminating the need for steel connections (dowels *etc*) and also permitting the application of a thin layer of new concrete or screeds –

even down to a feather-edge without problems of curling. It is interesting to note that new-to-old concrete bonding with epoxy resin systems was a fully accepted structural design practice in Japan in the 1960's, whilst it is still a rarity in the UK today[6].

The chemistry of epoxy resin adhesive for bonding uncured concrete is critical in that the resin-hardener system must have the right balance of hydrophyllic and hydrophobic properties to bond to moist concrete, whilst any free water at the concrete/resin interface must not reduce the bond strength of the resin significantly. In this application, tests have to be carried out at the temperature of application, since systems which have been widely recommended in the USA for bonding new-to-old concrete at application temperatures of around 20°C have proved to give rather poor bond strengths at cure temperatures around 10°C, which are not uncommon on UK construction sites.

Many of the epoxy resin formulations which have proved satisfactory for bonding new and old concrete have also proved suitable for application and cure actually under water. Although many polyester systems will cure well under water they generally do not bond reliably under wet conditions and are normally only recommended for bonding under dry conditions.

Construction adhesives

There are now many examples of the specification of resin adhesives at the design stage for the erection of structures, large or small, from pre-cast concrete elements, the adhesive being employed as a stress distributing bonding/sealing layer between the pre-cast elements, particularly for post-tensioned structures. Compared with more traditional cementitous mortar jointing techniques, resin adhesives offer several advantages including:

- Much faster development of strength, enabling more rapid removal of supports and post-tensioning to be commenced sooner.
- Greater tensile and shear strengths are obtained which can, in some instances, permit joined untensioned units to be assembled before lifting into place since the joined sections are as strong as monolithic concrete.
- Shrinkage of the adhesive is negligible and the joints remain waterproof (long-term).
- Thinner joints can be used (often less than 1 mm thickness) which are often not visible and, therefore, the structure may be aesthetically more pleasing.

The concept of using a stress-distributing resin adhesive in a major structure was pioneered in France by Enterprises Campenon Bernard in the construction of the Choisy-le-Roi bridge over the River Seine near Paris in 1962[7]. This bridge was made up of pre-cast concrete box units, 2.5 m long. The units were cast off-site in continuous lengths; one unit being cast against the next with a thin plastic film separator to ensure a perfect fit and that the thickness of the epoxy binding layer was kept to a minimum. On completion of the bridge, load tests were carried out which indicated that the epoxy-bonded segmental construction behaved exactly as a conventional *in situ* concrete structure, thus fully justifying the engineers' faith in the new design concept for such a large and critical structure.

Since 1962 many bridges in different parts of the world have been constructed using similar techniques employing epoxy adhesives including: a number of others in France; Kleinpolderplein Motorway Junction, Rotterdam, Holland 1968-70; Rio-Niteroi Bridge, Brazil, 1974-75, Rawcliffe Bridge, Yorkshire; Marron Bridge Cumbria, 1975-76; and Trent Bridge 1978-79[2].

In addition to bridges, segmental concrete construction techniques employing resin adhesives have been used in the construction of other structures including: Coventry Cathedral 1960-61; Sydney Opera House, 1963-67; Metallurgy Department Building, Birmingham University, 1965[8]; Gart Navel District Hospital, Scotland; and construction of Durban Sugar Terminal, South Africa[9].

In the main, the adhesives used for segmental construction have been based on epoxy resin compositions. However, polyester resin based adhesives have been used successfully on a number of jobs including the construction of a spiral staircase from pre-cast units at Castle Market, Sheffield in 1961 – one of the earliest resin adhesive applications in design in the UK[8].

General purpose adhesives

Resin adhesives have the capability of being able to bond dissimilar materials (adequately prepared), and because the resins themselves have good mechanical properties the thickness of the glue line is generally not too critical. Resin adhesives are extremely versatile and, therefore, in civil engineering, are very widely used[10]. Applications include concrete pile splicing, bonding old concrete to old concrete, glass to concrete, glass to glass, brick slips to concrete, metal cable carriers to concrete, road markers to concrete or bitumenous roads, and non-polishing anti-skid aggregate to slippery concrete or bitumenous roads[11]. Understandably, there is some reluctance on the part of engineers to rely purely on resin adhesives to be the sole means of transmitting tensile or tensile/shear stresses, particularly as optimum bond will depend upon a number of factors including surface preparation of the substrates to be bonded. Therefore, where resin adhesive bonding is to be the prime method of stress transfer, some limited mechanical connections are also often specified simply because the two fixing techniques working together give a more durable fixing than either on its own. Resin adhesives being of lower modulus than either concrete or steel can tend, if the adhesive joint is wrongly designed, to lead to failure by peeling action. This can be overcome by joints which are designed to ensure that the bond is stressed in such a way that a peeling action is avoided[3].

Structural mortars

Because of their high strength and rapid strength development, resin mortars have been used widely as bedding for bridge bearing pads and similar applications, and also as expansion gap nosings for highway bridge decks. Members of FeRFA are aware that over the past 10 years, there have been a number of problems associated with resin mortar beddings which have collapsed in service. After careful investigations it has been established that the great majority of problems have been due to mis-application – in particular, gross bad mixing of the resin.

In 1979 FeRFA published *Application Guide No 1* which gives both the specifying and site engineers detailed information on the points to look for when using resin mortar beddings.

Over the past fifteen years, epoxy resin mortars have been widely used as nosings for bridge expansion joints on major bridge construction projects in the UK. The idea was conceived by the Bridges Engineering Division of the Department of Transport in the mid 1960's as a much simpler and cheaper alternative to a large number of other complex nosing systems then being used, many of which were proving to be inadequate in service. The first epoxy resin mortar nosings were laid in 1964 and after three years' satisfactory proven performance their use was recommended in Department of Transport Bridges Engineering Technical memorandum BE6 in 1967.

In the late 1960's and early 1970's epoxy resin nosings were used very widely in major bridge constructions. This rapid increased usage of epoxy mortar nosings was not without problems, primarily due to mis-application but also, in some cases, due to some too-rigid and too-reactive resin compositions being used[12, 13]. The Technical Committee of FeRFA worked closely with the Department of Transport to resolve these formulation problems and now the Department of Transport have a list of registered epoxy resin mortar nosing compositions. These compositions were accepted by the Department of Transport after extensive site proving coupled with laboratory testing.

Until recently, all the epoxy resin mortar nosing compositions were based on graded aggregates of maximum size 2-3 mm at a filler: binder ratio of approximately 7:1 by weight (approximately 2.8:1 by volume), the maximum filler loading at which a completely void-free mortar with good application characteristics could be achieved with these filler gradings. However, in many instances, the thickness of the mortar nosings is well in excess of 100 mm and epoxy resin concrete nosings with graded aggregates up to 14 mm size and filler:binder ratio of approximately 11:1 by weight are now on the Department of Transport list.

Resin mortars are also used as bedding mortar or transition strips for many other proprietary mechanical expansion gap systems also used in the UK and other parts of the world.

In addition to bedding and nosing applications, resin mortars are widely used as heavy-duty floor finishes where their combination of excellent chemical resistance and good mechanical properties, in particular abrasion resistance, impact resistance, and resistance to very heavy rolling loads can be employed to the full[2].

Heavy duty resin grouts for the precision installation of machinery and crane rails

Resin compositions have been widely used as precision grouting compositions in the installation of heavy machinery and heavy duty crane rails. Filled resin compositions have proved excellent materials for transmitting heavy loads where the grout may be subjected to high tensile and tensile/shear stress, and also impact loads which cementitous materials are not able to withstand[14].

One of the first major uses of epoxy resin grouts in Europe was in the laying of the rails for the 840 tonne lifting capacity Goliath crane at Harland & Wolfe Shipbuilding dock constructed in Belfast in 1968-69, using some 200 tonnes or more of epoxy grout[15]. As a direct result of the confidence engendered by the Belfast crane application, resin grouting compositions have been widely specified and used for a number of construction projects in Europe. These include: grouting of the crane rails for a similar giant crane at Astilleros Espanoles SA at Puerto Real, Cadiz, Spain; seatings for bridge bearings of the reconstructed Britannia Bridge over the Menai Straits, Anglesey; grouting of the hinge plate seatings of Seaforth dock gates. Liverpool; and the relaying of the rails of the Radio Telescope at Jodrell Bank, all in the UK.

Resin grouts have also been used to completely re-lay or repair a high proportion of the crane rail tracks at freight depots in the UK, which handle the 6-12 m containers widely used in transport today. The need to repair was due, in most cases, to crane rails supported by cementitious materials proving to be incapable of carrying loads continually without problem.

Although most of the heavy-duty resin grouting compositions have been based on epoxy resins, polyester resins have also been used successfully, particularly in the repair field, because of their rapid strength development. Polyester grouts have enabled repairs to be carried out in a few hours and, therefore, often not interfering with commercial operations. If care is taken to apply polyester resin grouts in a non-continuous manner then any shrinkage which will inevitably occur, will not significantly affect the ability of the cured grout to transmit heavy loads in service without problems.

Resin grouts and chemical fixing for small-scale applications

Many jobs involving resin grouts are of a much more modest scale than those described above, but in terms of volume, the use of resin grouts for the installation of dowels, starter bars, holding down bolts *etc*, for small engineering and mining applications probably exceeds those used in precision grouting.

Pre-packed ready-to-use fully formulated polyester resins in the form of 'plastic sausages' or glass phials are widely used where a fixing is required into concrete, brick, masonry, block work, rock, or other material. A full strength fixing can be achieved within a few hours, and unlike mechanical fixings no torque load is required and corrosion of the installed fixing long term is not a problem. The concept of resin fixings is exceedingly simple; a hole of the right diameter and length is drilled with a rotary percussive drill, the hole is thoroughly cleaned of all loose material and a 'sausage' or phial is inserted into the prepared hole. The fixing, often in the form of threaded studding with a chisel end, is then screwed into a special driving unit attached to a drill and used to drive the studding down through the 'sausage' or phial, smashing up the packaging and mixing the resin as it drives through. The packages are available with different setting rates, from 3-30 minutes.

In mining and rock consolidating applications, steel or wooden dowels up to several metres long are regularly installed and here several packages of different setting rates are often used in one hole.

This concept of pre-packaging has only proved practicable for polyester resin systems as the degree of mixing achieved by rotating the fixing has not proved sufficiently intimate for epoxy resin compositions. However, there are many applications requiring the resin grouting of starter bars *etc* where pre-packaged material is not practicable. Two- or three-pack pourable or pumpable epoxy resin or polyester resin compositions have been used for grouting fixtures into floor slabs, and also on vertical and inverted surfaces. If properly installed, resin grouted fixings in good quality concrete are tested using a pull-out tester (failure occurs as a cone failure in the concrete).

As a rough guide, pull-out strength of the resin grouted fixings in 30 N/mm^2 concrete should be approximately one tonne per 25 mm length of embedment. In practice, service loads are generally far less, giving a safety factor of approximately 5:1, which experience has indicated to be more than adequate.

With polyester resin grouting systems, it is essential that both the fixing and the size of the drilled hole have a rough profile to ensure a good mechanical key. In addition, the hole diameters should not exceed the fixing diameter by more than approximately 12 mm. A suitably roughened hole is achieved by rotary percussive drilling. When fixing into diamond drilled holes, the holes should be routed out to give a good mechanical key, or, alternatively, grouted in with a suitable epoxy resin grout. Compared with polyester resin grouts, epoxy resin grouts have superior adhesion, and lower shrinkage, and fixings with hole diameters significantly greater than the fixing can be grouted satisfactorily, although holes with a reasonably 'tight' gap and some mechanical key should be used whenever possible.

Concrete repairs

Regrettably, much of the interest and use of resin compositions in the UK construction industry is still in remedial work rather than in design concepts. This remedial work may be the result of damage caused by unexpected external stress, but is more often the repair of components which are inadequate due to design errors or, most commonly, faulty workmanship. Without the unique properties of resin compositions many of the repairs undertaken would have been more costly and have taken much longer to carry out.

Before discussing materials and techniques used in concrete repair it is important to consider the cause of the defects requiring repair and having established it, employ repair materials and methods which will ensure that the repaired structure is cabable of withstanding similar stresses *etc* which caused the original defects, without problems[16].

Having established the cause and magnitude of the problem and the structural requirements of the repair coupled with information on the maximum acceptable time before the structure is returned to full service, the choice of materials to use and how to apply them can then be considered. The principal materials and techniques used include: surface preparation; sand/cement mortars (including polymer admixtures); resin bonding aids; resin injection; resin mortars; and resin bonded external reinforcement.

Surface preparation

One of the most important factors in achieving an effective concrete repair, regardless of materials to be used, is to ensure that the surface of the area to be repaired is properly prepared. In the experience of the author, lack of adequate surface preparation (or attempting to apply a repair material to a weak concrete substrate) has been one of the main reasons for poor repairs which have themselves broken down rapidly in service.

The importance of cutting-back the concrete to a clean sound surface cannot be over-stressed and, in the opinion of the author, requires far more attention than is often given in practice.

Sand/cement mortars

Although, in many parts of the world, polymers have been used in concrete repairs for many years, in many instances correctly designed sand/cement mixes, carefully placed, with good attention to detail, are still the most cost-effective repair materials. Also, regretfully, some polymer systems have been oversold or wrongly formulated for some applications where more conventional materials would have given improved performance at lower cost.

One of the principal causes of the need for major concrete repairs is spalling due to corrosion of the steel reinforcement. This is normally caused by ingress of water (or often water contaminated with de-icing salts) due to cracking, inadequate cover, or porous cover to the steel reinforcement. A good quality, well compacted sand/cement mortar with a sand/cement ratio 2-3:1 provides a high degree of corrosion protection for the thoroughly cleaned steel reinforcement, provided there is 25-30 mm cover (> 12 mm with polymer admixtures); below this depth of cover other materials need to be considered.

Resin bonding aids

In some instances, where it is decided to use a sand/cement mortar repair, a resin bonding aid can be of significant benefit. It is well known that sand/cement mortars, however well applied and cured, do have suspect adhesion and performance when 'feather edged' down from a thickness of over 30 mm to a few millimetres at the edge of a repair area, which is often the case in practice. By the application of an epoxy resin bonding 'tack' coat to the prepared concrete surface, it is possible to 'feather edge' sand/cement mortar repairs satisfactorily providing, of course, they are cured properly.

Resin injection

Both epoxy resins and polyester resins have been used to fill fine cracks down to approximately 25 μm width using gravity, pressure, and vacuum injection techniques. As with any concrete repair work, before any resin injection is undertaken, it is imperative that the original cause of the cracking is established.

Resin injection will, at best, only restore the strength of the structure to the original tensile strength and shear strength of the material at the crack interface, provided that the surface of the concrete, mortar, *etc* at the interface is clean and sound. Cracking is normally caused by either tensile or shear stresses and if these stresses re-occur after resin repair, all that will happen, since the tensile and shear strengths of the cured resin far exceeds that of concrete, is that the concrete will crack again somewhere adjacent to the repair. In such instances, the cause of these stresses must be rectified before the resin injected structure is returned to service. If this is not possible, then the crack has to be treated as a normal movement joint and filled with a very low modulus system, or the crack face sealed with a low modulus sealant based on polyurethane or polysulphide resins to prevent the ingress of moisture, and thus arrest further corrosion of steel reinforcement within the structure.

For resin injection, low viscosity epoxy resin systems are most commonly used and their use has been well proven for more than a decade.

The concept of epoxy resin pressure injection as a means of effectively repairing concrete beams *etc* structurally, has been investigated both in the laboratory and on site by testing cores taken from structures after injection. These investigations have confirmed that resin injection is an effective method of repair, and one leading firm of civil engineering consultants have concluded that properly carried out resin injection can, in some instances, restore the integrity of cracked concrete so that it falls within the *CP110* Code for concrete.

In general, the volume of resin used in injection applications is low. The combination of technical requirements of epoxy resin systems used in injection techniques tends to be somewhat different from that required for epoxy resin systems for other larger tonnage uses. As a consequence, epoxy resin systems which have been specifically developed for injection applications are often expensive and can prove costly if the volume of crack void is significant[2, 17, 18].

Low viscosity unsaturated polyester resins of similar specification to those widely used in glass fibre-reinforced plastic boat manufacture are significantly cheaper than epoxy resins and have been used in resin injection. However, such polyester resins which exhibit similar mechanical properties to epoxy resins but, in general, give lower bond strengths and do not cure reliably under damp conditions can, therefore, only be used in applications where the strength of the bond is less critical, such as injection into voids in low strength materials.

Resin mortars

Epoxy resin or polyester resin mortars have been widely used where the cover on steel is less than 10 mm, and for other structural repairs.

Polyester resin mortars bond well to dry concrete and are recommended for small areas of repair.

Epoxy resins, which are also widely used as protective coatings for steel in very aggressive environments, have been widely used in the field of concrete repair. Carefully formulated high strength epoxy resin mortars are available which bond very well under cold, damp conditions and have been used extensively in bridge construction and maintenance. By careful selection, systems can be applied up to 50 mm thickness in a single layer without problems of stress building up during cure.

Resin bonded external reinforcement

Over the past ten years, epoxy resin adhesives have been used to strengthen load bearing reinforced concrete structures by bonding on steel plate reinforcement. This concept was pioneered in South Africa[7] and has been used recently in the UK to strengthen bridges on the M5 at Quinton and the M25 Swanley Interchange[2].

Extensive testing carried out in a number of countries[7, 19] has demonstrated that significant increases in the strength of concrete beams could be achieved by techniques which were simple and practicable and which could be readily used for site repair work. The main requirements in strengthening structures by the external bonding is to achieve a sufficiently high shear strength at steel/adhesive/concrete interfaces. Laboratory work has demonstrated that when a relatively thin layer of epoxy resin is used to bond concrete to steel, failure, as expected, always occurs in the concrete adjacent to the concrete/resin interface at a shear stress of approximately $2 N/mm^2$.

Comment

In this paper it has only been possible to review the principal applications for resin compositions, However, it is hoped that the information given will make engineers more aware of the potential of resins in concrete construction and repair, and of the need to carefully select a resin composition for any particular application.

Acknowledgements

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References

1 **Lee, H. and Neville, K.** *'Handbook of Epoxy Resins',* (McGraw-Hill, New York, 1967)

2 **Hewlett, P.C. and Shaw, J.D.N.** 'Structural adhesives in civil engineering' in *Developments in Adhesives – 1* (Applied Science Publishers, 1977) ch 2

3 **Tabor, L.J.** 'Effective use of epoxy and polyester resins in civil engineering structures', *CIRIA Report 69* (1978)

4 'Methods of testing resin compositions for use in construction', *Document 81/13894* (British Standards Institution) (Draft prepared for public comment, October 1981)

5 **Sims, F.A. and Woodhead, S.** 'Rawcliffe Bridge in Yorkshire', *Civil Engineering and Public Works Review* (April 1968) p 385

6 **Tabor, L.J.** 'Concrete repairs', *Precast concrete* (February 1979) pp 65–68

7 **Muller, J.N.** 'Concrete bridges built in cantilever', *Ann Inst Tech Trav Publis, Supple 204* (1964)

8 **O'Brien, T.** 'Jointing structural precast concrete units with resin adhesives', *Int Symp: Synthetic Resins in Construction, RILEM, Paris, 1967*

9 **Fleming, C.J. and King, G.E.M.** 'The development of structural adhesives', *Int Symp: Synthetic Resins in Construction, RILEM, Paris, 1967*

10 **Gaul, R.W. and Apton, A.J.** 'Epoxy adhesives for concrete' *Adhesives age* (May 1970)

11 **Hatherly, L.H. and Lamb, D.** 'Accident prevention in London by Road Surface improvements', *World Highway Conference, Montreal, October 1970*

12 **Shaw, J.D.N. and Reader, C.E.L.** Symp: *Resins and Concrete, Newcastle upon Tyne, April 1973* (The Plastics Institute)

13 **Shaw, J.D.N.** 'Epoxy resin mortar nosings' Symp: *Advances in Concrete, University of Birmingham, September, 1971* (The Concrete Society)

14 **Goodhall, P.D. and Husband, H.C.** 'Grouting in structural engineering and the application of epoxy resins', *Struct Engnr* (December 1972)

15 **Bromley, D. and Woodward, J.C.** 'Use of epoxy resin formulations as self-levelling grouts' Symp: *Resins and Concrete, Newcastle upon Tyne, April 1973* (The Plastics Institute)

16 **Allen, R.T.L.** 'The repair of concrete structures', *Cement and Concrete Association, Publication No 47.021* (1974)

17 **Gaul, R.W. and Smith, E.D.** 'The effective and practical structural repair of cracked concrete', in *'Epoxies with concrete' Special Publication No 21*)American Concrete Institute, 1968)

18 **Kreigh, J.D.** 'Arizona slant shear test', *J Am Concrete Inst* **73** No 7 (1976) pp 373-377

19 **Irwin, C.A.K.** 'The strengthening of concrete beams by bonded steel plates', *TRRL Report SR 1600C* (Department of the Environment, Department of Transport, Crowthorne)

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