The chemistry of chemical anchors: how different chemical formulae affect the installability and long-term performance of chemical anchors

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Abstract: There are a multitude of different chemical anchors available in the Australian construction industry and with that many different chemical formulations. Typically, the types of base chemicals used are epoxy, vinyl ester, polyester and hybrid formulations.

The molecular structure of these chemicals give rise to the different long and short-term properties of the anchors. Long term behaviours of the cured chemical include resistance to harsh chemicals and corrosive environments, service temperature ranges, resistance to fire, interaction with the environment, and the loading capacities that the anchor system can achieve. In the short term the chemical formulation will affect how long it will take to achieve full cure, at what temperature the chemical can be installed and the dispensability of the product. It will also influence how sensitive the chemical is to hole condition, diameter and depth.

The range of chemical anchors offered by manufacturers can be confusing to both designing engineers and to the contractors installing the fixings, and can lead to incorrect substitution of one anchor type for another. This paper will consider the chemical anchor types available in the Australian market, and investigate how their general chemical formulation affects their short and long-term properties in order to clarify what applications and environments they should be specified for.

Keywords: chemical, anchor, epoxy, acrylate, fastener

Introduction

Post-installed anchors are used in the construction industry to affix structural and non-structural members to in-situ and precast concrete once the concrete has cured. Chemical anchors use adhesive and cohesive bonding to achieve their hold into the concrete as opposed to mechanical anchors which rely on either expansion or keying to make the connection. Chemical anchors are typically selected because of their high capacity, flexibility in terms of embedment depths and the ability to position them closer together and nearer the edge of the concrete. However, different chemicals have different properties which will affect their behaviour in the short-term during installation and also in the longer term with regard to their capacities and resistance to environmental conditions.

The different chemistries have their pros and cons and manufacturers will produce a range of chemical anchors suitable for different applications. Typical formulations include epoxies, vinyl esters, epoxy acrylates, polyesters, and hybrids containing organic and inorganic materials.

Short term behaviours include the time taken to achieve gelling and full cure, dispensability of the product, installation temperature, and sensitivity to hole condition, diameter and depth. Long term properties of the cured chemical include the load capacity, resistance to harsh chemicals and corrosive environments, service temperature ranges and resistance to fire.

These short and long term behaviours are dictated by the chemical formulation and it is useful to have deeper understanding of why they behave the way they do in order to specify and use the correct chemical anchor for the application and environment. Manufacturers will introduce additives to influence some of the properties but generally the chemical anchors available in the Australian market fall into the following categories.

Figure 1 Heavy duty chemical anchor

Types of chemicals used for concrete anchors and their chemistry
Epoxy

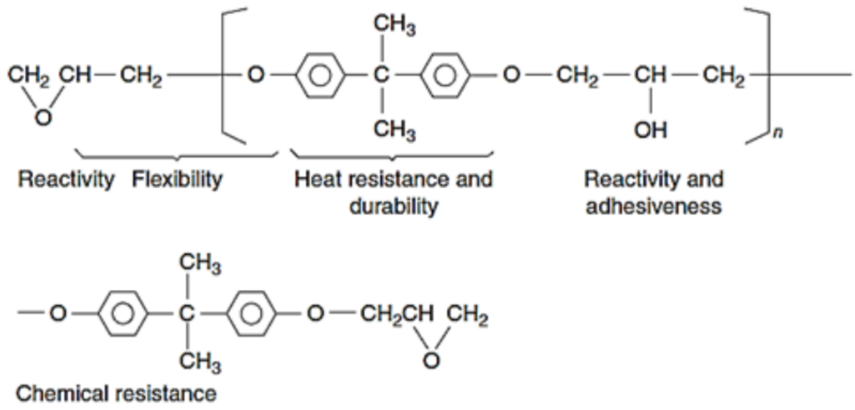

Figure 2 Example of an epoxy chemical formulation

Epoxy resins contain an epoxide (a 3 atom highly reactive ring), functional groups that may react with themselves or a wide range of other molecules such as alcohols, thiols, acid anhydrides, amines and phenols. This cross-linking reaction between these hardeners is known as curing.

The strong molecular bonds between the larger chemical groups leads to a strong chemical bond both within the epoxy and with other materials. This high bond strength also leads to excellent durability including their resistance to extreme temperatures and their chemical resistance.

For chemical anchors into concrete substrates the high bond strength contributes to the high loading capacity. However, the bonding capacity is enhanced by their fluidity which allows them to penetrate the minute interstices or the pores on surface of the concrete and in some cases the silicates and aggregates within the concrete mixture creating a physical bond. The components by nature have a lower comparative viscosity in the uncured state which can be enhanced by the use of solvents. The physical properties of the epoxy allow it to be used in applications where the hole has a relatively smooth surface, in particular core drilled applications. In chemical anchoring a threaded stud, sleeve or deformed reinforcement bar is installed into the two-part chemical mixture; the steel elements lack significant porosity and therefore rely on the deformations in the steel itself or thread to provide physical resistance when the epoxy cures and finally hardens.

Certain epoxy formulations are more surface tolerant and less effected by moisture. In the case of flooded or wet hole applications, there is a small subgroup of chemical ring structure amines that maintain all the benefits of the amines group of chemicals while removing moisture attracting properties of typical amines. This unique group of polyamines form the basis for epoxy adhesives used in applications where water is present.

The epoxy adhesive curing process has minimal by-products of the hardening reaction. This results in minimal loss of mass as a by-product of the reaction and thus shows relatively no shrinkage in the curing process. This then allows the epoxy to be used in application where large diameter reinforcement and anchors are used at deeper embedment. This characteristic of the adhesive epoxy also allows for applications or errors that require use with larger annular gaps and will have little or no reduction in anchor capacity.

The chemical reaction between the hardener and the epoxide is a relatively long process. This will also be due to the nature of the formulation in the 2-part mix. Differing functional groups in the reactive mixtures will have different cure times. This will determine reactive timeframes along the curing process such as the gel time. During this phase the initial molecular chains are still mobile, and the epoxy resin can be worked with. The gel time can range typically between 15 to 30 minutes at 20°C. This will be affected by the ambient and substrate temperatures where the product is being used. The cure time is longer than for other chemical anchors; for example, at 20°C a fast curing epoxy will harden at approximately 8 hours where a standard formulation may take 24 hours to harden and cure. It is therefore important to note the temperature of both the substrate and ambient environment when using such products.

The activation temperature for the epoxy reaction must be above 0°C for the product to perform at to its specified parameters. Thus, epoxy chemical anchors are sensitive to low temperatures ranges during the installation and the curing process. The speed at which the product cures is therefore also affected by substrate and surroundings temperature; the lower the temperature the longer the cure time.

Both the gel and curing rates also influence the applications that epoxy anchors are suited for. In deep embedment applications for post-installed reinforcement, the fluidity enables the bar to be installed into the chemical with relative ease. The longer gel time allows the bar to be pushed in before the epoxy has set and is also helpful when dealing with multiple application sites. This is also relevant when larger diameter and deeper embedment is required and gives the ability to install anchors with a larger annular gap. Longer gel times and the lower viscosity at this point in the reaction helps to ensure that there is good coverage between the bar / anchor and substrate. Longer gel times also allow the installer to ensure the bar has been placed orthogonally to the substrate. On the other hand, in overhead applications the fluidity and longer gel time can be a disadvantage and other measures should be used to contain the chemical and stud or bar in the hole.

Vinyl ester, epoxy acrylate

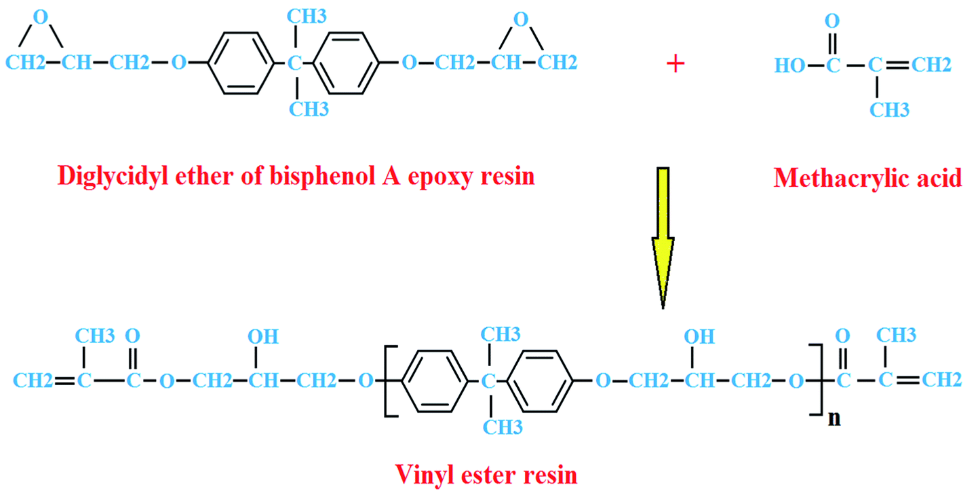

Figure 3 Example of a vinyl ester chemical formulation

A vinyl ester resin is a thermoset matrix resin that is considered a hybrid of epoxy and polyester. It is a molecular chain that consists ester groups double-bonded to vinyl groups. The base of the polyester resin is strengthened by the epoxy molecules in the backbone of the molecular chain. Vinyl ester resins have the characteristics of both the workability of the epoxy resin and the fast cure of the polyesters. However, they differ from polyesters in terms of the location of the reactive sites. Because vinyl ester is a resin produced by the esterification of an epoxy resin with acrylic or methacrylic acids they can also be known as epoxy acrylates.

The presence of the epoxy chains brings with it many of the advantageous properties of a pure epoxy, such as durability, chemical and temperature resistance. The quicker curing rate of the polyester element reduces time that the chemical bonds can form, which equates to a reduction in the bond strength to some extent, when compared to a pure epoxy.

As vinyl esters have fewer open sites in its molecular chain, it has the ability to repel water. This makes it resistant to water penetration which can cause osmotic blistering of the adhesive. Thus these chemical anchors can be used in flooded and wet holes providing they have been tested; anchoring capacities may have reduction factors that apply.

Vinyl esters will shrink a little more than epoxies due to the way they form the structure based on their intermolecular bonding. This shrinkage is still relatively small and is insignificant in its effect on bond strength in limited diameters and annular gaps; however, if the annular gap around a chemically bonded fastener in the concrete is increased the vinyl ester shrinkage will reduce the anchor's performance significantly.

As vinyl esters have a lower activation energy than epoxies, it allows the adhesive to initiate the reaction and perform at lower temperatures. In some cases, formulation dependant, this allows the end user to work in environments that are below zero Celsius. Generally speaking, these are not common conditions in which we find adhesive chemicals being used in Australia.

Hybrid chemical anchors

Some manufacturers describe their formulations as hybrid formulations due to the addition of inorganic fillers to one of the components. They have similar performance characteristics to vinyl esters; however, the incorporation of inorganic fillers can enhance the properties, Cleaver (1)

Polyester

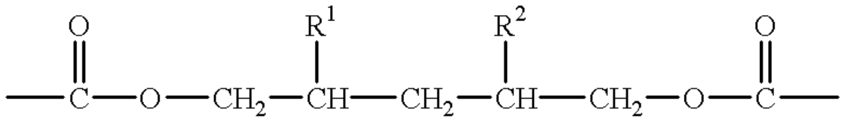

Figure 4 Example of a generic polyester chemical formulation

Unsaturated polyester adhesives, when sold in cartridges, are mainly two-part systems that harden by the addition of a catalyst, usually a peroxide such as methyl ethyl ketone peroxide. Polyester adhesives usually have a solvent component (up to 4-5%) of their overall composition. They have a faster curing process and usually have a weaker strength compared to epoxy systems due to the nature of the chemical reaction and its components; the cross bonding of vinyl esters is far better than that of polyesters. However, it should be remembered that in relation to performance, polyesters are only the lowest capacity in a group of the very high-performance adhesives.

Whilst polyesters may not be as robust in terms of performance as epoxies, they are still a functional solution and high performing adhesive. Strong molecular bonding with the mix allows them to operate in chemically challenging environments which also includes temperature variations. Generally speaking, polyesters are not as resistant to water ingress than other solutions; however marine grade formulations have a greater ability to resist the effects of water when applied.

As with vinyl esters, the structure formed by polyester as it cures causes some shrinkage which is acceptable for small annular gaps. However, its bond capacity in oversized holes and smooth cored holes is significantly reduced due to the afore mentioned attributes. Likewise, this limits its suitability in larger diameter connections. The viscosity and thixotropic nature of polyesters, similarly to vinyl esters, enhances their suitability for overhead connections but limit their use in deep embedment post installed reinforcement. Their higher activation temperature compared to vinyl esters means that they are sensitive to low temperatures ranges during installation and curing.

Importance of correct installation

Once the various properties of a range of chemicals have been considered and an anchor selected for the connection, it is important that the installation of the chemical anchor is carried out correctly. There are some key performance and application characteristics common across all chemical anchors available in the market. The hole should be drilled correctly and cleaned thoroughly to manufacturer's instructions. Ideally this can be achieved by using a dustless drilling system where dust and debris are removed by vacuum at the time of drilling. Alternatively, the hole should cleaned by both blowing and brushing the dust out of the hole a number of times until there are minimal particular contaminants present. These steps will be outlined in the installation instructions as per the manufacturer's guidelines of use.

The chemical resin and hardener components need to be thoroughly mixed to ensure the product performs as specified. For injection chemical anchors this will require discarding the first few trigger pulls of the chemical mixture until a uniform homogeneous mix is observed. For epoxy grouts both components should be mixed in the container for the required length of time. For chemical capsule anchors the resin and hardener will be mixed in the hole itself during installation.

The ambient, substrate and chemical temperatures should all be considered when selecting which chemical anchor to use since the chemical reaction is temperature dependent; but this value will vary between chemical formulations and products. It is also important to ensure that the chemical product is used within its shelf life date to avoid a decrease in performance outside the specified range.

Validation of chemical anchor products

AS 5216:2018 Design of post-installed and cast-in fastenings in concrete (2) requires that chemical anchors should be tested for suitability and admissible service conditions in accordance with European Assessment Document EAD 330499 (3), typically by achieving a European Technical Assessment. It is through this process that a manufacturer will achieve various approval criteria for a chemical anchor including use in cracked concrete, seismic qualification, 50 year or 100-year design life. Within a manufacturer's product range they may have more than one product with a broadly similar basic chemistry (but variations of exact molecular composition); however, they may not elect to have the same level of testing and assessment for all products in the range.

Conclusion

The physical properties of chemical anchors are dictated by their chemical formulation and although each have their advantages and disadvantages. It is important to select the correct product for the application which it is designed for. Overall, for optimum long term performance in most environments experienced within the construction industry, epoxy anchors provide the best solution with the highest load capacities, chemical and temperature resistance, but also allow for installation flexibility because they can be used in larger, deeper holes with larger annular gaps. However, their higher cost and longer curing time can be can contribute to increased costs on the project. Vinyl esters, hybrids and epoxy acrylates still offer good load capacities along with good chemical and temperature resistance, but with shorter cure times; however, shrinkage during curing precludes their use in oversized anchor holes and larger diameters. Polyesters have a shorter cure time and provide a useful solution when load capacity is less critical, but shrinkage will again prevent their use in larger holes.

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