A GATE INTO

EPOXIES

PREPARED BY: -

BRWA ABDULHAMEED

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REFERENCES

- ACI 503
- ACI 548
- ACI CT-18
- FDOT-PART 416
- USE OF EPOXIES FOR GROUTING REINFORCING BAR DOWELS IN CONCRETE
- GUIDELINES FOR EPOXY GROUTED DOWELS IN SEISMIC STRENGTHENING PROJECTS
- CHEMISTRY AND TECHNOLOGY OF EPOXY RESINS
- EPOXY ADHESIVE FORMULATIONS

Key Definitions:

- ACICT-18 definition for "Epoxy"
  A thermosetting polymer that is the reaction product of epoxy resin and compatible hardener.
- ACICT-18 definition for "Epoxy resin"
  A class of organic resin which when combined with compatible hardener is used in the preparation of special coating or adhesive or as binders in epoxy mortars, epoxy grouts, epoxy concrete and fiber-reinforced polymer composites.
- Definition of "Adhesive" according to "Chemistry and Technology of Epoxy Resins":
  An adhesive as be in a material which when applied to substrate surfaces can join them together and resist separation.

INTRODUCTION

The use of structural adhesives in the manufacture of load-bearing components has grown extensively in recent years. This can be attributed to a number of desirable qualities which adhesive bonding allows in comparison with more traditional joining techniques as riveting and welding. These include:

- Allowance of a relatively uniform stress distribution, resulting in improved fatigue performance.
- The ability to join dissimilar substrate materials which, due to their dielectric nature, minimizes the possibility of electrolytic corrosion between dissimilar metals.
- Allows the joining of thin-gauge metals to each other, in particular honey comb assemblies, resulting in the availability of light weight structures exhibiting high strength to weight rations.
- Allows both increased design flexibility and the ability to fabricate complex shapes.
- The possibility of reduced production costs in comparison to welding and riveting.

(Reference: Chemistry and Technology of Epoxy Resins)

A STRUCTURAL GREAT QUESTION

Arising reinforced concrete accompanied by several obstacles, such how to embed steel in to hardened concrete.

For the first time in the history in the middle of 19^{th} century, it was done, dowels were embedded with epoxy as ACI503 states in the section 2.3.3.2 of the report (Use of epoxy compounds with concrete) but the great question is: Is it allowed to embed dowels with epoxy?

The answer is: Yes, and here are the evidences

- ACI503 in the mentioned report- section 6.4 writes: "epoxy resin is a good adhesive for most materials used in construction such as concrete, masonry units, woods, glass and metals".
- ACI548 under the title "Specification for bonding hardened concrete and steel to hardened concrete with an epoxy adhesive “allows steel embedment into concrete with epoxy.
- FDOT- part 416 which is an American resource allows this action under the title "Installation of post installed anchor system and dowels for structural applications in concrete elements".
- A report from Texas University since 1985, has accepted this idea under the title "Use of epoxies for grouting reinforcing bar dowels in concrete "
- A research which refers to ninth world conference for seismic engineering allows the idea under the title "guidelines for epoxy grouted dowels in seismic strengthening projects".

IMPORTANT NOTES TO EMBED DOWELS

- The best results for cleaning were obtained when the hole was cleaned with stiff brush and thoroughly vacuumed. Vacuuming from the top the holes were found to be no better than no cleaning at all. By using nozzle that could reach all parts of the hole, thorough vacuuming improved the dowel pullout strength considerably.
- Samples were taken from different manufactures, it was noted that, "how to mix" in the all of products are the same: using a mixer with a velocity (400-600 rpm).

  The signs of good mixing are: Homogenous color, No air bubbles

- in general, the higher the temperature the shorter the working time and the greater the early strength gain.
- The diameter of the drilled hole should be just large enough to allow proper placement of the rebar and grout. Large holes cannot be justified economically. holes should be drilled with a rotary percussion drill whenever possible to create a rough surface. If core or diamond drilling is required redrilling by a rotary percussion drill is recommended. Pre formed holes are not recommended unless redrilling is done. Holes must be free of dust. Wire-brushing, compressed air flushing and water flushing have been mentioned as good methods. If possible, a method should be employed to obtain the effects created by sandblasting.
- Previous studies indicate that bar diameters should be greater than 0.5 inch and less than 1 inch. Also recommended that a maximum load of 55kips per bar be allowed for a reinforcing bar anchorage system.
- Dowel spacing can be determined by three methods:

1. A chart developed by the epoxy manufacturer.
2. A minimum of two times the embedment length.
3. some multiple of dowel diameter, recommended using a spacing of 20 times the bar diameter.

(Reference: Use of Epoxies for Grouting Reinforcing Bar Dowels in Concrete)

SURFACE TREATMENT PRIOR TO BONDING

Surface treatments can be divided in to three broad areas, these being associated with solvent cleaning, mechanical abrasion and chemical treatment

- Solvent cleaning: is concerned solely with the removal of organic contaminants (greases, oils, etc.) from the surface.
- Mechanical abrasion: approach to surface treatment can be regarded as incorporating processes by physical mechanical means without having any significant impact on the chemistry of the surface.
- Chemical treatment: removing the existing perhaps inherently weak and unstable oxide layer and generate a new oxide layer conductive to both good adhesion and stability.

(Reference: Chemistry and Technology of Epoxy Resins)

CLASSIFICATION OF EPOXIES

-According to Using

1. For use in bonding hardened concrete and other materials to hardened concrete.
2. For use in bonding freshly mixed concrete to hardened concrete.
3. For use in bonding skid resistant materials to hardened concrete and as a binder in epoxy mortars or epoxy concretes.

-According to Being influenced by temperature in the moment of using

1. For use below 40º F.
2. For use between 40º to 60º F.
3. For use above 60º F.

-According to Viscosity

1.Grade I --- low viscosity --- 20 poise

2.Grade II --- medium viscosity --- 100 poise

3.Grade III --- high viscosity --- sagging consistency 0.25 in

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(Reference: Use of Epoxies for Grouting Reinforcing Bar Dowels in Concrete)

CHARACTERISTICS OF GOOD EPOXY

In the field of civil engineering the consumption of conventional materials such as concrete, wood, metal and glass are astronomical. Epoxy resins exhibit excellent adhesion to these materials and therefore have been used widely for surfacing, coatings and for repairs. The most frequent applications of epoxy resins in civil engineering include:

- Flooring.
- Road and Bridge coating.
- Concrete bonding and repair: use of epoxy resin formulations as concrete bonding and repairing materials finds application over much wider areas than just bridges and roads. Virtually any structure with concrete as its primary construction material will develop cracks with age. Epoxy formulations can be coated on to the surface to prevent the initiation of such cracks and also to repair existing cracks. Structural defects occurring in other materials such as wood, brick and metal can also be repaired by epoxy formulation.

Good epoxies have these characteristics:

- They exhibit excellent adhesion to most metallic alloys and various other substrate types.
- They are capable of operation at temperature up to approximately 150Cº for both short and long-term applications.
- They are highly versatile in the sense that a wide range of processing cure and property characteristics can be achieved.
- They cure by reaction mechanisms which do not result in the generation of volatile by-products.
- The exhibit good wetting properties when applied to well-prepared surfaces and exhibit relatively low shrinkage during cure. --

(Reference: Chemistry and Technology of Epoxy Resins)

ADVANTAGES, DISADVANTAGES OF ADHESIVE BONDING

There are many alternatives to adhesive bonding that a manufacturer can employ such as screw, rivets and spot welds. Each potential joining process must be considered with regard to its specific requirements. There are times when adhesives are the worst possible option for joining two subtracts and there are times when adhesives may be the best or only alternative. Usually the choice of joining process is not all black or white. Certain plastics may require expensive surface preparation process to allow the adhesive to wet the surface. On the other hand, certain applications could not exist without adhesive bonding. Example of these are the joining of ceramic or elastomeric materials. There are also certain applications where adhesives are chosen because of their low cost any easy, fast joining ability.

The science of adhesive bonding has advanced to a degree where adhesives must be considered an attractive and practical alternative to mechanical fastening for many applications. Advantages and disadvantages are summarized as below

1-ADVANTAGES

- Provides large stress bearing area.
- Provides excellent fatigue strength.
- Damps vibration and absorbs shock.
- Minimizes or prevents galvanic corrosion between dissimilar metals.
- Joins all shapes and thicknesses.
- Provides smooth contours.
- Seals joints.
- Joins any combination of similar or dissimilar materials.
- Often is less expensive and faster than mechanical fastening.
- Heat, if required is too low to affect metal parts.
- Provides attractive strength to weight ratio.

2-DISADVANTAGES

- Surface must be carefully cleaned.
- Long cure times may be needed.
- Limitation on upper continuous operation temperature.
- Heat and pressure may be required.
- Jiges and fixtures may be needed.
- Rigid process central is usually necessary.
- Inspection of finished joint is difficult.
- Useful life depends on environment.
- Environmental, health and safety consideration are necessary.
- Special training sometimes is required.

(Reference: Epoxy Adhesive Formulations)

LAP-SHEAR SPECIMEN

this test in its various forms is probably the most commonly employed method for evaluating adhesive joint strength.

Type A: Single lap-shear joint

Type B: Double lap-shear joint

Type C: Scarf joint

(Reference: Chemistry and Technology of Epoxy Resins)

THEORIES OF ADHESION

Four main theories have been proposed to account for the phenomenon of adhesion

a. Mechanical interlocking.
b. Electrostatic.
c. Diffusion.
d. Adsorption theory: of all theories proposed to account for the phenomenon of adhesion, the so-called adsorption theory is the one which has achieved more general acceptability within the adhesion fraternity and which can be said to offer the greatest relevance to adhesive bonding with epoxies. The basic tenet of adsorption theory is that, provided sufficiently intimate intermolecular contact is achieved between two materials, they will adhere because of surface force interactions between the atoms in the two contacting materials.

(Reference: Chemistry and Technology of Epoxy Resins)

FILLERS

They are used in epoxy adhesive formulations to improve properties and to lower cost. Properties that can be selectively improved include both the processing properties of the adhesive as well as its performance properties in a cured joint. However, the use of fillers can also impair certain properties. Typically, the formulator has to balance the improvements against properly decline. The advantages and disadvantages of filler additions and the properties that they are used to modify are shown below:

1- ADVANTAGES

- Lower cost of product.
- Reduced shrinkage on curing.
- Decreased exothermic temperature on curing.
- Improved tensile shear strength.
- Increased surface hardness.
- improved abrasion resistance.
- Improved heat-aging properties.
- Increased electrical strength.
- Improved toughness if fibrous fillers are used.

2- DISADVANTAGES

- Increased weigh
- Increased water absorption "depending on filler"
- Loss of transparency
- Difficulty in machining hard fillers

(Reference: Epoxy Adhesive Formulations)

Here are some fillers and their capability of property modification.

FILLER	PROPERTY MODIFICATION
Aluminium	impact resistance
Aluminium silicate	chemical resistance
Aluminium trioxide	flame retardation
Beryllium oxide	thermal conductivity
Carbon black	thermal conductivity
Copper	electrical conductivity
Quartz	electrical properties
Silica	moisture resistance
Sand	abrasion

(Reference: Chemistry and Technology of Epoxy Resins)

ADHESION PROMOTERS

are group of specialty bifunctional compounds that can react chemically with both the substrate and the adhesive. The adhesion promoter forms covalent bonds across the interface that are both strong and durable. Adhesion promoters can be applied directly to the substrate, similar primers, or they can be mixed with the adhesive itself. When mixed into the adhesive formulation, adhesion promoters are sometimes referred to as coupling agents because they can interact with both the substrate and the other fillers in the formulation when mixed with the adhesive, the adhesion promoter is capable of immigrating to the interface and reacting with the substrate surface as the adhesive cures. When applied directly to the substrate, adhesion promoters are used as a very thin coating that ideally is only one molecular layer thick.

Adhesion promoters can also be applied to mineral fillers or fibers prior to their addition to a formulation.

The adhesion promoter provides for a formulation that has several unique benefits:

1- Enhanced processability, shown by reduced viscosity easier flow and lower energy required to compound and mix.
2- Increased tensile, flexural and impact strength.
3- Better retention of these properties under adverse temperature and humidity conditions over long period of time.

(Reference: Epoxy Adhesive Formulations)

SUBSTRATES THAT PROVIDE FORGOOD EPOXY ADHESION

Metal: aluminum, copper, stainless steel, nickel

Plastic: Polycarbonate, Polyester, Phenolic

Elastomeric: Nitrile, Neoprene, Urethane

Other: Glass, Ceramic, Wood, Concrete

METAL BONDING

Metals having a relatively high surface energy are generally considered easy to bond. However, several problems could occur when one is working with metallic substrates. These are related to the following characteristics:

1- Durability related to the environment effects on the substrate surface and the interface of the adhesive joint.

2- Variation in the surface chemistry depending on alloy processing, preconditioning, etc.

3- Relatively low thermal expansion coefficient and high thermal conductivity compared to most epoxy adhesives.

One difficulty in bonding metal is the durability of the joint. It is not much a problem of making a strong joint as one of keeping it that way throughout its expected service life. A weld may have strength of only 600 Ib, but it is likely to remain that strong far 5 to 10 years afterword.

An epoxy adhesive, on the other hand, may have 3 to 4 times the initial strength of a weld but it could weaken when exposed to high humidities, cycled between hot and cold temperatures, or immersed in salt water and then dried. By definition, a structural adhesive must be able to withstand these conditions without significant deterioration.

A second difficultly in bonding metals is that only the surfaces are involved. Adhesives and sealants are active only on the molecular surface layer that forms the joint interface and, on any surfaces, contained in the porosity of the metal itself. Thus, if unprepared steel is being bonded, it is not the bulk iron-carbon alloy that is being bonded, but the iron oxide layer on the surface.

ALUMINUM

Is an almost ideal substrate for adhesive. It has high surface energy and is very resistant to most environments. It is also a material with good formability and high strength-to-weight ratio that can benefit greatly from properties offered by adhesive joints. As result, adhesive bonded aluminum joints are commonly used in the aircraft and automotive industries. Bonding of aluminum most likely compromises the majority of the applications for epoxy adhesives. Aluminum joints are also commonly used in adhesive studies and for comparison of different adhesive materials and processes. Adhesive manufacturers literature generally describes the properties of bonded aluminum joints. However, the corrosion resistance of aluminum as well as the durability of joints made with epoxy adhesive is very dependent on the type of aluminum alloy used. Bonds made with relatively corrosion-resistant 6061-T6 aluminum alloy will last about 4 times as long as equivalent joints made with 2024-T3 alloy when exposed to marine environments. However, with the proper combination of surface treatment and adhesive, these differences in durability to aggressive environments can be minimized. The oxide layer that forms on aluminum is more complex than with other metal substrates. Aluminum is a very reactive surface and oxide forms almost instaneausly when a freshly machined aluminum surface is exposed to the atmosphere. Fortunately, the oxide is extremely stable and it adheres to the base metal with strength higher than could be provided by most adhesives. The oxide is also cohesively strong and electrically nonconductive. These surface characteristics make aluminum a desirable metal for adhesive bonding and they are the reasons why many adhesive comparisons and studies are done with aluminum substrates. The strength of an epoxy adhesive aluminum joint can be improved by cleaning the surface to remove contaminants or by converting the existing surface to a new surface that may be more consistent. In the case of the aluminum surface chemical conversion can also protect the base metal from corrosion and enhance the durability of the bonded joint to various service environments.

COPPER

Copper substrates are commonly bonded with epoxy adhesives in the microelectronics and marine industries compared to aluminum substrates, copper when bonded with epoxy adhesives provides lower initial strength. Depending on adhesive and the type of test used. This can be as much as 50 percent lower. Similar to aluminum joints, copper joints bonded with epoxy adhesives can show poor durability in moist environments unless the interface is protected. Copper is used in three basic forms: pure alloyed with zinc (brass) and alloyed with tin (bronze). Copper and copper alloys are difficult to bond satisfactorily, especially if high shear and peel strengths are desired. The primary reason for this difficultly is that the oxide that forms on copper develops rapidly (although not as fast as the rate of oxide development on aluminum). The copper oxide layer is weakly attached to the base metal under usual conditions. Thus, if clean bare copper substrates were bonded the initial strength of the joint would be relatively high, but on environmental exposure an oxide layer could develop which will reduce the durability of the joint. Cleaning and mechanical abrasion are often used as pretreatments for copper and its alloys where low to medium bond strength are acceptable. For optimum bond strength and permanence, the oxide layer must be specifically engineered for adhesive bonding. This is often done through what has been called the "black oxide" coating process or through chromate conversion coating. Brass and bronze, sand blasting or other mechanical means of surface preparation may be used for both of these copper alloys. Surface treatment combining mechanical and chemical treatment with a solution of zinc oxide, sulfuric acid and nitric acid is recommended for maximum adhesion properties. Adhesives similar to these recommended for copper may be used on brass and bronze substrates.

STEEL AND IRON

Because of their widespread use in industry, steel and iron are frequently bonded. Like the surfaces of most metals, their surface actually exists as a complex mixture of hydrated oxides and absorbed water. Unfortunately, iron oxides are often not the best surface for adhesives because the oxides may continue to react with the atmosphere after and adhesive has been applied, thus forming weak crystal layers. Iron oxides are more difficult to engineer than aluminum, copper or titanium oxides. As a result, grit blasting is used in most applications, although it provides adequate adhesion and durability for many applications, grit blasting does not provide great durability in severe environments. Conversion coatings are often used in these cases. Bonding operations frequently require the mechanical or chemical removal of loose oxide layers from iron and steel surfaces before adhesives are applied. To guard against slow reaction with environmental moisture after the bond has formed, iron and steel surfaces are often phosphated prior to bonding. This process converts the relatively reactive iron atoms to a more passive form that is coated with zinc or iron phosphate crystal. Corrosion protection is critical in bonding steel even more critical than for many other metallic adherents. The initial adhesion to steel is usually good but deteriorates rapidly during environmental conditioning. Thus corrosion-preventing primers are usually recommended because they protect the surface against changes after bonding.

PLASTIC BONDING

Plastic are usually more difficult to bond with adhesives than are metal substrates. Plastic surfaces can be unstable and thermodynamically incompatible with the adhesive. The actual bonding surface may be far different from the expected substrate surface. The plastic part can possess physical properties that will cause excessive stress in the joint. The operating environment can change the adhesive-plastic interface, the base plastic, the adhesive or all three. However, even with these potential difficulties adhesive bonding can be an easy and reliable method of fastening one type of plastic to itself, to another plastic, or to a nonplastic substrate. Significant differences in the thermal expansion coefficient between the substrate and the adhesive can cause severe stress at the interface. This is common when plastic are bonded to metals because of the difference in thermal expansion coefficients between the substrates.

ELASTOMERS

There are over 30 broad groups of chemical types of elastic polymers; there are several problems with joining elastomer materials. Elastomer materials specifications usually do not focus on the adhesive properties, but mainly address the chemical and physical properties of the rubber. One problem in joining elastomers with adhesives is that since they are deformable materials, it is easy to develop internal stresses at the bond interface. These stresses could adversely affect the bond strength and the permanence of the joint minimal pressure to achieve close substrate contact with the adhesive is all that is necessary when bonding with elastomers.

WOOD AND WOOD PRODUCTS

Wood is an important structural material. adhesive are commonly employed to bond wood in furniture industry. They are increasingly being used in laminating and veneering of wood-based products onto composited panels. Sealants are commonly applied to wood framing members in the construction industry. Several properties are unique to these materials that will affect their ability to be joined. Tensile and shear strengths of wood are greater along the longitudinal direction, parallel with the wood fibers. Maximum performance is achieved if the wood has a moisture content during bonding that is close to the average moisture content anticipated during service. In this way, the internal stresses induced in the joint as a result of moisture change in service will be at a minimum. Therefore, wood substrates are generally preconditioned to a known moisture content before bonding. Wood changes little in dimension as a result of temperature changes unless such changes also affect the internal moisture content. Wood of different species will vary considerably in density or specific gravity. Higher density wood of any species is usually stronger than wood of a lower density, higher-density wood swells and shrinks more for a given moisture content than wood of lower density. This means that internal stresses on high-density wood joints are greater as a result of swelling and shrinkage effects than between two pieces of wood of lower density with the same joint design. Such internal stresses maybe sufficiently large to pull the apart. Therefore, higher quality joints must be developed when one is bonding higher density wood. Generally, it's desirable to have the adhesive joint as strong as or stronger than the wood itself, particularly for structural applications. Several important rules need to be remembered when one is joining wood. Good fitting joints are critical. A thin even layer of adhesive will form a strong bond between two pieces of wood but a thick cushion of adhesive generally weakens the joint.

GLASS AND CERAMICS

Glass and ceramic substrates are generally high-surface energy materials and most adhesives wet them readily.one problem in bonding optically clear glass is to select an adhesive that is optically clear and does not change the optical characteristics of the glass. Another problem is that shrinkage of the adhesive or differences in thermal expansion coefficients could provide high internal stresses that cause catastrophic failure of the brittle glass substrate. Adhesive used for glass substrates are generally transparent, heat-setting resins that are water and UV-resistant to meet the requirements of outdoor applications. They are usually flexibilized systems so as not to place stress on the glass substrate either after cure or during thermal cycling. Adhesives for glass or ceramic to metal seals should never become fully rigid because thermal expansion rates for adhesives are much higher than those for the bonded materials. Temperature changes can lead to high stresses, which can cause cracking and joint failure.

CONCRETE

Concrete provides a substrate surface that changes during its cure and also during environmental exposure. The main difficulty with bonding concrete is due to the presence of moisture. This moisture can be retained in fresh concrete and may be present in old concrete due to the environment. Concrete is a substrate whose surface characteristics are also likely to be affected by the environment in which it cures. The surface can be different depending on the temperature and humidity conditions during the cure of the concrete. Once it is cured, concrete has several surface characteristics that are problems for bonding or sealing. It often has a weak, porous surface layer that must be penetrated or removed before being bonded. Thus, sealers and primers are commonly used moisture-proof and strengthen the concrete surface prior to bonding. The substrate should be free from contaminants while old concrete does not need to be thoroughly dry any standing water must be removed before the adhesive is applied. Adhesives commonly used on concrete must be formulated so that they cure well in the presence of moisture. The adhesive should have a viscosity that allows it to penetrate the concrete for mechanical bonding.

(Reference: Epoxy Adhesive Formulations)