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ADHESIVE BONDING TECHNIQUES IN HYBRID STRUCTURES MADE FROM FIBRE REINFORCED POLYMERIC COMPOSITES AND CONCRETE

BY

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Abstract. Mechanical joining techniques are used in construction industry all over the world on a daily basis. A further method of joining has proven to be highly successful – adhesive bonding. Known for thousands of years, adhesive bonding has become as important as other joining techniques as a result of the pace of developments in recent years. In many areas, this bonding technology has become a key technology. Virtually, all solid materials can be connected with one another using adhesives.

Although bonding fibre reinforced polymeric composites to the concrete substrate is a relatively simple technique, the proper installation of the fibre reinforced polymeric composites is essential to ensure the adequate performance of the hybrid system. Since the installation procedures differ from one system to another, appropriate specifications will be clearly presented. The paper will include requirements to provide a quality joint assembly, meaning the special pre-treatments of the concrete surface. The material to be bonded is cleaned and prepared so that adhesives can adhere better to them.

Key words: Fibre reinforced polymeric composites (FRP); concrete; adhesive; hybrid structures; bonding techniques.

1. Introduction

The twentieth century has already seen incredible technological advances, some of which have resulted in profound changes in the construction industry. New materials have been introduced, new manufacturing methods have enabled traditional materials to be used more efficiently or more cheaply, and the demand for other traditional materials has declined.

Fibre reinforced polymeric (FRP) composites exploit the advantages of high tensile strength fibres and are characterized by excellent corrosion resistance, fatigue resistance, low densities, and high specific stiffness and strength [1]. Commonly used fibres include E-glass, Kevlar/aramid, and carbon; these can be preimpregnated in matrices, lined unidirectionally in tow sheets, or woven into bidirectional fabrics [2].

FRP composites are bonded to the structural elements chemically through adhesives, the steps involved in the bonding operation being described in Table 1 [3]. Application usually involves preparation of the concrete surface through mechanical or chemical means followed by a primer. Chemical bonding is the most practical because it does not induce stress concentrations, is easier than mechanical devices to be installed and it does not damage neither the base material nor the composite.

Table 1
The Different Steps in a Bonding Operation

Steps	Operations
1. Preparation of substrates	a) Cleaning b) Abrading, chemical surface treatment c) Conditioning of materials before bonding
2. Preparation of adhesives	a) Addition of fillers b) Dilution and adjustment of viscosity c) Mixing the components
3. Coating/dispersing	a) Brush, towel b) Spraying c) Roll application (manual or automatic) d) Application of adhesives
4. Drying, waiting time, open time	a) Waiting for evaporation of solvents or water
5. Heat reactivation of the adhesive	–
6. Assembly of parts	a) Hand made or automatic
7. Pressing	a) Time, pressure and temperature b) Manual (clamps) roll or platen press c) Cold or hot pressing
8. Curing, hardening	–

2. Adhesive Bonding

Adhesive bonding provides flexibility in design and in the use of different materials. Some combinations can be fastened only with adhesives.

Three advantages are offered by bonded assemblies over conventional construction namely

a) more efficient use of material to save cost, weight, and volume;

b) opportunity to preassemble building components to save time and onsite labour;

c) improved performance by achievement of more rigid joints to develop the full strength of materials.

With rigid adhesives, the hybrid system has a strength and stiffness far greater than the sum of the individual members, and greater than when assembled with mechanical fasteners. Structural components bonded with adhesives can be designed with smaller members than when mechanical fasteners are used. This advantage is best demonstrated in sandwich panels, where thin, strong faces are bonded to thick, lightweight core material. These systems represent highly efficient construction through adhesive bonding. However, the advantages of adhesive bonding can only be attained through an exact attention to each stage of the bonding process. If adhesives are not used knowledgeably, or are applied without sufficient care, the advantages of bonding may be supplanted by such disadvantages as erratic or unsatisfactory performance [4].

The quality of any adhesive bond depends both on the selection of the proper adhesive for the application and on the bonding conditions under which that adhesive is used. The best adhesive in the world will not produce consistently high quality joints if it is used improperly. In practice, more of the poor joints encountered are the result of poor bonding conditions than of some deficiency of the adhesive, provided the proper adhesive was selected. The quality of joints is, then, a responsibility of both the adhesive user and the adhesive manufacturer [5].

3. Concrete Surface Preparaion

In all too many cases, the substrate is considered to be a constant throughout the life of a production part. But in practice, substrate surfaces are full of surprises, often they contain constituents that are very different from the bulk material, thus the behaviour of the hybrid structure heavily depends on a good substrate and the preparation of its surface.

Concrete surface preparation is a critical parameter in the bond performance of the adhesives materials applied to concrete. Proper surface preparation provides a dry surface to avoid the presence of dirt, dust, oil and grease. Even moisture can absorb onto the surface of the substrate or onto the freshly applied adhesive to form a weak boundary layer [2], [6].

Thus, above all else, one must start with a clean, strong surface. Removal of surface contaminants allows primers and repair materials to have direct contact with the substrate and not with these weak boundary layers. The remained concrete should be sand-blasted or cleaned using high pressure water jet.

A rough surface provides more bonding area than a smooth gross dimension. The greater effective surface area offers a larger area for the forces of adhesion to operate, thereby providing a stronger joint. However, a greater degree of surface roughness could also contribute to stress concentrations in the adhesive joint, similar to a notch effect in metals. This effect depends on how well the resin wets the surface and penetrates into the surface roughness [5].

All surfaces to which the composite is applied should be dry according to the fibre reinforced polymeric system manufacturer's requirements before the resin system can be applied. Water in the concrete pores may inhibit resin penetration and reduce mechanical interlocking. The moisture content should be evaluated in accordance with the requirements of [7]. Generally, concrete is considered to be dry 24 h after the removal of the surface water [8].

Rectangular cross-sections should have corners rounded or reshaped to a minimum radius of 35 mm to prevent stress concentrations in the FRP sheet and voids between the FRP composites and the concrete substrate. Roughened corners should be smoothed with an epoxy gel.

Debonding or delamination of the FRP system can be resulted from an improperly prepared substrate concrete, before achieving the design load transfer. However, relevant standards and guidelines should be used for detailed methods for repair and surface preparation of concrete [9].

4. Preparation of the Adhesive

Adhesives come in various forms, and most of them require some mixing or other preparation for use. Popularity of the elastomeric adhesives and polyvinyl–resin emulsion systems (the so called “white glues”) in disposable cartridges is due largely to their ready-to-use form. Types which require mixing include casein, urea-resin, resorcinol-resin, epoxy-resin, polyvinyl emulsions of the cross-linking type, and some polyurethane adhesives. Follow the manufacturer’s instructions for mixing, but usually the adhesive components are to be mixed by weight.

In case of adhesives which require water mixing, the best procedure is to add the powder to the water gradually, with adequate stirring. Power mixers are best for larger batches. Small batches can be stirred by hand with suitable paddles. Resorcinol or phenol–resorcinol resins are usually sold as syrups to which a specific weight of powdered hardener is to be added. Such solid hardeners should be added gradually to the liquid resin while stirring, as for the water-base systems just described. Epoxy resins and some polyurethane resins require the addition of specific amounts of a separate hardener or curing agent, usually in liquid form [5].

An important factor to consider is the working life of mixed adhesives. The working life is the length of time that an adhesive remains spreadable and usable after mixing. Normal working life is usually indicated in the manufacturer’s literature. The working lives of resorcinol resin adhesives or of epoxy-resin adhesives may vary from an hour or so to as much as several hours, depending on formulation and temperature of the mix. Because of the chemical reactions in such adhesives, the working life decreases as the temperature of the mix increases [4].

In the case of a thermosetting resin adhesive, the adhesive will set hard shortly after gelation has rendered the mix unworkable. It will then become difficult or impossible to remove from containers and spreading equipment. Solvents will not dissolve such highly reacted resins. It is important to recognize this and to mix only as much adhesive as can be used during the working life. Then, clean up equipment and spilled material before it hardens. It is impossible to thin down and continue using reactive adhesives at the end of the working life. Some of the reactive adhesives, particularly the epoxy resins, may undergo considerable internal heating after mixing due to exothermic reactions.

Thermoplastic adhesives used for building construction are similar in several respects. They are not recommended for bonded joints that will be highly stressed because most of them are susceptible to creep.

5. Bonding Technique

The method of application of the adhesive will depend on particular system and structural configuration. Generally hand methods are used, though machines have been developed for wrapping columns [2], [6]. For plates, a layer of adhesive is usually applied to the plate while fabrics are usually pre-impregnated. Sufficient pressure is applied with rollers to ensure a uniform adhesive layer and to expel any entrapped air. For complex surface geometries where preformed plates cannot conform, vacuum-assisted resin infusion can be used to form the composite *in situ*. The fibres are applied to the structure dry. The area is sealed with a rubber sheet and vacuum used to draw in the resin [10].

If a fabric or tow sheet is used, an epoxy is applied to the concrete followed by the fibre in a process called wet lay-up. Here, the adhesive is also the matrix, creating a stronger bond but also subjecting the fibres to debonding stresses with uneven concrete surfaces. Pre-impregnated fibre reinforced polymeric sheets and plates may be roughened, and then attached to the concrete with an epoxy layer. Here the choice of the adherent stiffness is crucial for effective stress transfer to the laminate [11].

A good practical guide on spread is to observe the appearance and amount of squeeze out of adhesive when pressure is applied to the joint. If sufficient adhesive has been spread and pressure is then applied within permissible time limits a thin line of droplets of adhesive will be visible along all exposed joint edges. Absence of such squeeze out indicates insufficient spread or too long a delay before pressure application. Excessive adhesive running down the edges of the joints indicates that an excess has been spread, that the adhesive is too dilute or that pressure has been applied before the adhesive developed sufficient tack.

Spreading joint areas can be done effectively in some instances with stiff-bristle brushes, with paint rollers, or with a metal spatula. For larger areas, as in laminating large beams, mechanical roll spreaders may be desirable. The important point is to apply sufficient adhesive in a uniform layer. The bead thickness will be influenced too by the speed of application.

The assembly period is the time interval between spreading the adhesive and applying full bonding pressure. The studied hybrid system is a closed assembly and it refers to the time after the two spread surfaces are joined, but before they are pressed. Manufacturers usually cite maximum permissible assembly periods for several temperatures, and these limitations should be observed.

Bonding performance may be diminished by assembly periods which are too short as well as by those which are too long. Many liquid adhesives are fairly low in viscosity when mixed and must thicken to some degree in the joint before pressure is applied. The setting rate of reactive adhesives may be adjusted by choice of resin varieties, choice of hardeners, and amount of hardeners [4].

Also, control of adhesive and substrate temperatures, and of ambient temperature at assembly point, can be used to affect the assembly time.

5. Conclusions

FRP composites are bonded to an existing structure to enhance its strength. The material type of that structure is the substrate. For an ideal bonding surface between the substrate surface and the matrix we have to consider five common criteria: strength, cleanliness, continuity, stability, and wetting capability.

To obtain strong, uniform, adhesive-bonded joints, preparation of the surfaces to be bonded is necessary. To provide the necessary degree of adhesion, the surface to be bonded should be clean. Generally, it should be smooth and well fitted to the adjacent surface to permit economical, thin bond-lines. Good fitting will also provide maximum opportunity for the applied pressure to distribute the liquid adhesive over the entire joint area. The resultant even spreading will help assure good adhesion.

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TEHNICI DE ÎMBINĂRI ADEZIVE LA STRUCTURILE HIBRIDE DIN COMPOZITE POLIMERICE ARMATE CU FIBRE ŞI BETON

(Rezumat)

În întreaga lume, în mod cotidian, sunt utilizate în industria construcţiilor tehnicile de îmbinare mecanică. O metodă suplimentară de îmbinare s-a dovedit a fi de mare succes: îmbinarea adezivă. Cunoscută de mii de ani, îmbinarea adezivă a devenit la fel de importantă ca şi alte metode de îmbinare, ca rezultat al progreselor înregistrate în ultimii ani. În multe domenii, această tehnologie de îmbinare a devenit una cheie. În principiu, toate materialele solide pot fi conectate unele de altele folosind adezivi.

Cu toate că lipirea compozitelor polimerice armate cu fibre pe substratul de beton constituie o tehnică relativ simplă, aplicarea corespunzătoare a compozitelor polimerice armate cu fibre este esenţială, în vederea asigurării performanţelor conforme sistemului hibrid. Din moment ce procedurile de montaj diferă de la un sistem la altul, vor fi prezentate specificaţiile corespunzătoare. Lucrarea va include cerinţele necesare asigurării calităţii îmbinării, cu precădere referindu-se la pre-tratarea suprafeţei de beton. Materialul ce urmează a fi lipit este curăţat şi pregătit astfel încât adezivul va putea asigura o aderenţă superioară.