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Technical Note

USE OF FIBRE COMPOSITE MATERIALS IN EXTERNAL STRENGTHENING OF CONCRETE STRUCTURES

INTRODUCTION

Fibre reinforced plastic or polymer (FRP) repair and strengthening systems are a combination of fibre reinforcing material and resins such as epoxies and other adhesive materials, which can act as a composite to enhance the capacity and extend the life of concrete structures. The role of the resin is to provide the adhesive bond onto the concrete surface and facilitate the transfer of stresses to and from the fibres. The use of FRP composite materials for the strengthening of reinforced concrete structures has been gradually increasing since the technique was first used in Japan in the mid 1980's. In recent times however, the use of FRP composites has gained momentum and is increasingly overtaking steel plate bonding and other established strengthening techniques. Amongst other applications, FRP composites are now being used to increase the flexural and shear capacity of beams and slabs and the axial load, bending, shear and confinement capacities of circular columns. Compared to steel plates, FRP composites are thinner, lighter, non-corrosive, exhibit much higher tensile strength and are much easier and quicker to install without the need for expensive and disruptive temporary support systems. FRPs are much more appropriate for curved applications such as circular columns and can be applied over longer lengths without requiring overlapping or connections.

FORMS OF FIBRE REINFORCED POLYMER (FRP)

The important fibres used for external repair and strengthening are carbon, aramid and glass. Their selection for particular applications depends on many factors including their individual properties, the type of component to be strengthened, loading history, temperature and moisture conditions and other environmental effects. In selecting the type of fibre to be used, consideration should be given to such factors as chemical resistance, compressive strength, elastic modulus, impact resistance, resistance to ultraviolet light, fire resistance, electrical conductivity and so on. Further advice should always be obtained from the suppliers of strengthening materials. The performance of FRP systems can be greatly influenced by the volume, type and orientation of fibre used, quality control during manufacture, the type of resin used and dimensional effects. At this stage no standard design code is available for FRP composite systems.

FRP composites are available in a number of forms as follows:

(i) Poltruded FRP plates generally made with continuous carbon fibres taken through a resin impregnation bath and a heated die shaping process which consolidates the combination and cures the resin. Plates formed by poltrusion are produced with a high fibre content, have a uniform cross-sectional shape and are of a consistent quality. They are generally 1 to 2 mm thick, supplied in widths generally in the range of 50 to 100 mm and can easily be cut to length on site.

(ii) Poltruded FRP strips or sheet material are made of either carbon or aramid fibres in a resin matrix. These are in the form of either parallel unidirectional fibres or woven rovings for two directional properties on a removable backing sheet. The strips can be as thin as 0.1 mm thick and up to 500 mm wide and can be provided in the form of a coil, which can be easily cut to length.

(iii) Reinforcing fibres (either carbon or aramid) in sheet or roll form pre-impregnated with a resin (prepreg process), which can be heat cured once in place. These have relatively high fibre content in the longitudinal direction and may incorporate some glass fibres diagonally to improve the handling of the material. The rolls can be up to 12 m long and thicknesses up to 30 mm can be achieved.

(iv) Fabrics or flexible sheets (dry or with a small amount of factory applied resin) can be used in wet lay-up FRP systems to form thick laminate applications. On site the dry fabric/sheets are saturated with resin mechanically or manually and placed by hand to form a composite laminate. This is a very adaptable technique and can be used for strengthening of columns and completely surrounding the sides and soffits of beams. However, it is very labour intensive and requires experienced personnel to undertake the work. Proper orientation of the fabric/sheet, adequate saturation with resin, removal of air pockets and initial pretensioning of the material are critical to the in-situ performance of the system.

PREPARATION OF CONCRETE SURFACE

The long term performance of FRP composite applications is dependent on the soundness, proper preparation and profiling of the concrete surface in order to enhance the intimate contact and adhesion strength at the interface. Inadequate surface preparation can result in debonding of the FRP system and therefore failure to effect the design load transfer of the overall composite system. Effective preparation is normally undertaken using wet or dry grit blasting (eg. garnet). For maximum adhesion it is important that the preparation process removes the surface layer of concrete to expose small particles of aggregate, surface roughness should be between 0.5 mm to 1 mm. However, the surface should not be roughened excessively. In addition, the prepared surface must be free of dirt, oil, grease, laitance, fungal or mould growth, previous coatings or curing compounds. The whole area should then be cleaned of any dust by blowing with compressed air. Where fabric is to be wrapped around corners, the corners should be rounded to a minimum of 25 mm radius or as recommended by the supplier to avoid local damage to the fabric. A trial surface preparation should be undertaken and a sample of an acceptable surface kept for ongoing comparison for the duration of the works. In addition, trial installation of the overall FRP system on portions of the structure should be part of specified requirements.

SURFACE CONDITION AND ENVIRONMENTAL REQUIREMENTS

The prepared concrete surface must be relatively flat such that the gap under a 2 m straightedge should not exceed 5 mm. Any out of tolerance areas should be rectified with a suitable rapid setting leveling epoxy. Any defects should be rectified using suitable cementitious repair materials in accordance with the manufacturer's recommendations. Proprietary cementitious repairs should be cured for at least 14 days before undertaking any FRP application. Cracks greater than 0.2mm should be epoxy injected in accordance with VicRoads Standard Specification Section 687 “Repair of Concrete Cracks”. Environmental checks which must be determined and be acceptable prior to FRP application include air temperature (5^{O}C - 35^{O}C), concrete surface temperature (8^{O}C - 35^{O}C), relative humidity (<85%), dew point (3^{O}C below concrete surface temperature), concrete surface moisture condition and moisture content of concrete (less than 8%). The concrete surface should be dry prior to the application of the FRP system unless special consideration has been given to the adhesive to be used.

APPLICATION OF FRP COMPOSITES

The mixing and application of the adhesive (resin and hardener) should be in accordance with the manufacturer's instructions. The adhesive must be mixed at the correct speed and in the correct proportions with a suitable mixing paddle. Where FRP plates are being used some abrasion of the surface may be required as per the manufacturer's recommendations unless the plates are manufactured with the required roughness. The adhesive layer is applied to the plates in a curved profile with approximately 3 mm in the centre and 1 mm on the edges to reduce the risk of void forming. For the application of dry fabric/sheet the mixed adhesive is rolled or brushed onto the concrete surface. The dry fabric is then applied to the resin-saturated surface without any adhesive applied to the fabric. For wet fabric/sheets (some factory applied resin) the resin is applied onto the fabric before it is installed with hand held foam rollers, brushes or impregnation machines.

Installation of FRP plates is effected by applying uniform pressure by roller along the longitudinal centerline and working outwards to expel excess adhesive at the edges and produce an even adhesive line. For fabric/sheet application the fabric is rolled to force the adhesive through the fibre to remove wrinkles and to expel any air. Subsequent layers are applied in a similar manner to form the required laminate. Fabrics may subsequently be protected as required or as recommended by the manufacturer. The minimum overlap for plates or fabrics/ sheets should be in accordance with specified requirements or the manufacturer's recommendations.

END PERFORMANCE TESTING

Testing for the performance of FRP composite systems during installation should include an ongoing delamination survey to check for drummy areas, testing for flatness of the finished product, placement tolerances and adhesion (pull-off) testing. The drummy survey should be conducted at a high frequency using a small hammer. Such frequency can be relaxed if no failures are detected. When drummy areas of FRP application are identified, rectification should be undertaken in accordance with the designer's directions and by agreement of the Superintendent. Testing for flatness should be done using a 2 m straightedge. The final product should not deviate from the 2m straightedge by more than 5mm. Rectification can be effected by additional fabric application as determined by the designer. Pull-off adhesion tests should be carried out on sacrificial pieces of FRP composite (same conditions and quality as final product) following the satisfactory curing of the resin adhesives. Minimum acceptable bond strengths should range between 1.4 MPa and 2.5 MPa depending on the quality of the concrete and the acceptable mode of failure. As such, the minimum tensile strength of the concrete should be 1.4 MPa and its minimum compressive strength not less than 15 MPa. In-situ load testing may be considered to validate improved load capacity.

DURABILITY OF FRP COMPOSITES

The technical literature suggests 30 years as the design life of fibre composite materials. However, the overall long-term performance of FRP systems may be affected by a number of environmental factors, including temperature, humidity, moisture effects and chemical exposure. Such factors would have an effect on both the FRP fibres and, the adhesives depending on the resin type and formulation. Because of the lack of long term experience of the performance of fibre composite strengthening systems, regular inspection, monitoring and maintenance regimes should be put in place.

SUMMARY

Although FRP composite strengthening systems are a relatively new technology they can provide durability and long term performance, provided they are correctly chosen, designed, specified and installed. The success of the FRP system installation is highly dependent on the quality of the on site practices adopted and therefore work should be undertaken by trained personnel who are competent in the installation procedures developed by the manufacturer of the particular FRP system. Adequate inspection and testing should be undertaken on a frequent basis as part of an overall quality assurance and quality control program.

REFERENCES

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