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FRP SHEETS CONTRIBUTION IN COMMON REPAIR TECHNIQUES OF CONCRETE STRUCTURES WITH EMPHASIS ON CONCRETE COLUMNS

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ABSTRACT

The history of composites dates back to few thousand years ago. Actually, natural fibrous composites were used by ancient Egyptians to build small houses. Numerous studies have revealed that Fibre Reinforced Polymer (FRP) is a convenient material for repair and strengthening of concrete structures compared to the traditional materials. Since the presentation of fibre reinforced polymer (FRP) in the concrete structures, the need for practice codes containing FRP in field of strengthening and repair has emerged. Many parts of structures are usually replaced simply, instead of repair due to the lack of knowledge about the techniques of repair. Hence, in this review, advantages and disadvantages of FRP repair, different types of FRP repair systems, repair stages and principles of repair theory for concrete structures with FRP are reviewed. In addition, modern repair techniques are reviewed in detail for different damaged levels of concrete structures. Recent developments in the field of repair with FRP have highlighted the need for assessment of repaired concrete columns. Thus, in one part of this review, the authors emphasise different damaged concrete column repaired with CFRP**.** Finally, the recent needs for further researches in field of repair with FRP are discussed.

Keywords: *Column, Concrete, FRP, Repair*

1.0 INTRODUCTION

The history of composites dates back to few thousand years ago. For example natural fibrous composites were used by ancient Egyptians for building small houses in form of straw-reinforced-clay bricks. Besides, fabricating natural compression was used as a cross-ply papyrus papers in improving the linen wrapping method for their mummies to increase the flexibility of the dried brittle dead bodies as shown in Figure-1 [1].

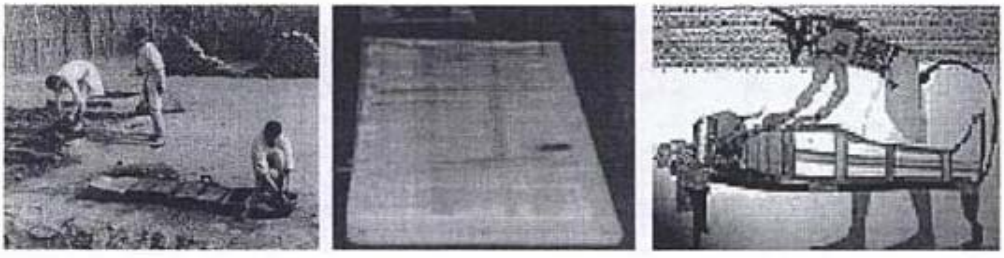

Figure 1: Ancient Egyptians utilization of natural composites: a) Fibrous clay blocks, b) Compression moulded cross-ply papyrus sheets, c) Mummies linen wrapping systems [1].

Recent developments have concentrated on the mixing of continued fibre-base textiles with mortars instead of resins which is leading to the textile-reinforced mortars (TRM). Both FRP and TRM material are called, continuous fibre composites. They are also known as advanced composites or simply composites. The applications of FRP as structural reinforcement have increasingly become common in construction in many countries [2]. The development of practice codes containing FRPs has its limitations in the wider range of application. Nowadays, the market for externally bonded FRP has a dynamic situation. Several types of manufactures are working in this market part, while researchers and institutes are trying to obtain design guidelines for FRP. The ranges of FRP applications in civil structures have been become very wide. Hence, various difficult projects have been done by using FRP, such as tripling the bearing capacity of a floor slab in Belgium, strengthening of silos in Sweden, seismic strengthening in Greece and Italy [3].

Many researches about the application of FRP have been carried out in Europe since 25 years ago. Most of the European activities have focused on externally bonded FRP reinforcement (FRP EBR). In Switzerland alone, the amount of FRP material used for strengthening in structures reached 30 to 50 km per year until 2000 [4]. From 1980s FRP has been utilized in Japan for different application of repair and strengthening. Its application has increasingly developed to the level that nowadays it is using in many modern construction projects and researches in the world due to their low labours costs, light weight, high tensile strength to weight, and easy installation [5]. Moreover, new types of products and methods have been introduced in the market to develop the feasibility of FRP repair and strengthening methods such as L shaped carbon FRP strips for shear strengthening, methods for improving anchorage capacity by mechanical devices, methods to use prestressed FRP for external bonded reinforce [4]. In this review, advantages and disadvantages of FRP repair, different types of FRP repair systems, repair stages and principles of repair theory for concrete structures with FRP are reviewed. In addition, modern repair techniques are reviewed in detail for different damaged levels of concrete structures.

2.0 APPLICATION OF FRP

FRPs have many advantages in outdoor and indoor for structure applications. Firstly they are very rigid, strong with outstanding strength compared to their weight. Secondly, they present a high creep resistance in the long term. They are highly resistant to temperature change without softening or brittleness. They are also good resistance to UV radiation, humidity, atmospheric pollution. Apart from having a low flammability depending on the choice of resin, the material has also a good thermal resistance and a good dimensional stability. Users use a wide range of possibilities in terms of colour and different form of good design. Furthermore, FRPs can be used in construction as lightweight materials. Hence, they are easy to carry. FRPs can also be used as prefabricated elements, which are easily and rapidly joined without the need of special handling equipment [6, 7].

3.0 REPAIR CONCEPT

Repair of defective parts of concrete structures is still an issue among the researchers due to the different levels of damage. The method of repair depends on the type and size of damaged area. For example a small damaged area can be simply repaired with epoxy and resin [14]. For large area of damaged in terms of depth, usually the repair mortar are utilised to fill the defective part of concrete member. For this type of defect, two parts of material from different source are joined together. Hence, this type of damages is weaker than small size damage after repair. The most common types of FRP repair systems are wet lay-up, pre-cured, and near surface method [14, 15].

The quality of repair depends on the bonding between surface and FRP. Hence, the quality of the epoxy and resin affects the bonding stress. For original parts of structure, the resin which is used between FRP and surface cures chemically as a uniform unit. This is primary and strongest

bonding between concrete and FRP. Since usually some parts of concrete structures are damaged, the repaired part becomes secondary bonding connected to the original primary structure. Thus, repairs parts are only as strong as the adhesive utilised to connect the damaged parts to the original parts. As a result, for repair, the stronger adhesive resins should be used [6, 16-18].

Repair influences by quality of adhesion to the primary structure. Hence, durability and strength of repair depends on the amount of surface area where is utilised for bonding. Nowadays different style of FRP structures are used for strengthening and repair of concrete structures such as fully wrap, spiral strap, district strap. These differences are mostly due to FRP price which is expensive. In the strap style, the amount of utilised FRP is less than fully wrap. For repair, the amount of surface area where is repaired by FRP affect the bonding. Thus, among these styles, fully wrap style is convenient for repair. As a repaired part of structure becomes thicker, it becomes stiffer. Hence, due to the lack of flexibility, the FRP are peeled. As a result increase of number of FRP sheets layer should be avoided for repair [17, 19, 20].

4.0 REPAIRS ON CONCRETE STRUCTURES

Based on the demand, in different situations, repair of concrete structures is needed due to the lack of ductility, durability, stiffness and strength. The most common situations that a concrete member needs repair are listed below [8-11].

- Seismic repair
- Damages due to the accidents and environmental conditions
- Change of application
- Initial design flaws

FRP repair method is more convenient and economic compared to the traditional repair methods. It can be utilised either to repair some damaged parts of concrete structures or to strengthen concrete structural members such as beam, column, wall, and slab to resist higher load especially for seismic upgrade [5]. FRPs are convenient material for corrosion problems of concrete structures. Khaled et al points out FRP sheets can be used to repair of corroded reinforced concrete beams to maintain structural integrity. However, these experimental results are achieved based on variable chloride levels from 0 to 3% [12]. Carbon and glass FRP are convenient material to repair of unreinforced masonry walls. By utilising carbon or glass FRP on the exterior surface of the wall, both flexural and shear capacity of masonry walls can be increased. The advantages of FRP using for masonry walls are increasing out-of-plane flexural strength, increasing stiffness at service loads, adding very little weight to the wall, and limited access requirements.

However, evaluation of long-term properties of FRP is difficult. Additionally fatigue, potential of FRP to be damaged against the ultraviolet radiation, high price of FRP and low modulus of elasticity for aramid and glass fibres are still potential disadvantages of FRP repair methods. Hence, application of FRP repair method is limited due to these disadvantages [13].

5.0 METHODOLOGY OF REPAIR ON CONCRETE STRUCTURES

5.1 TO FIND THE LEVELS OF DAMAGE

Damage usually devotes into four groups. The most common types of structure damaged levels are tears, crushed cores, punctures, and delaminations. For realize the type of damages, coin tap test is commonly used. Detection of crushed material and solid laminate is easy with audible differences [7].

5.2 DETERMINATION OF REPLACEMENT OR REPAIR OF DAMAGED PART

To inspect the level of damaged area, the size of damaged area is important. Estimating of the type of material and labour time needed for repair is the best way to find which option of replacement or repair is more convenient according to the estimated price [6, 7, 17].

5.3 TO PREPARE THE AREA SURFACE FOR BONDING WITH REMOVING THE DAMAGED MATERIAL

Coin tapping should be used until all damaged concrete layers are removed from surface. As far as possible, little material must be removed to avoid repair grows up too large. Nevertheless, concrete surface must be exposed for a strong repair. In this stage, concrete surface must be prepared with sandpaper or cup brush depending on the surface area before repair with FRP. Any remaining dust must be vacuumed and the concrete surface should be wiped with solvent rag. Normally, air-compressor is used to remove the small pieces of materials inside the cracks. Acetone is convenient to remove dusts, grease, oil, waxes, or other contaminants which would affect repair adhesion. Open time, pot life, and curing duration must be considered for mix of epoxy and resin before sticking the FRP sheets. For over coating with FRP, when a part of FRP is damaged, it is difficult to realign the fibres together, because after damage, FRP composites fibres tend to hang up on each other [7, 21-23].

5.4 LOOKING OVER FOR REPAIRING

Coin tap method should be utilised to check the cured repair. The entire parts of concrete structure should resonate the same sound. Non-destructive load test should also be used for more confidence [23-25].

6.0 CONSIDERATION ON COLUMN REPAIRWORK

Recently, the technique of repair and strengthening of RC column with steel jackets has been widely replaced by FRP sheets. The most common form of FRP for repair of column involves the external wrapping of FRP sheets. According to the previous researches, FRP-confined concrete behaviour is different from steel confined concrete. Hence, design manual and standards for steel-confined concrete column cannot be used for FRP-confined concrete column [26-32].

FRP repair method is based on providing confinement for column to increase its strength and ductility. The significant of FRP confinement action is enhancement of the ductility and strength of concrete column. It should be emphasised that enhancement of ductility is more important than strength in terms of seismic upgrading. It also prevents slippage and buckling of the longitudinal reinforcement for concrete columns. In seismic problems, repair techniques for upgrading are usually based on confinement pressure for the entire column or potential plastic hinge regions. FRP fully wrap can only increase tri-axial compression for concrete column which is not enough for seismic upgrade [13, 33].

Numerous studies have attempted to model compressive behaviour of FRP-confined concrete. In reinforced concrete columns confined with FRP jackets, concrete is loaded under tri-axial compression and FRP is loaded in hoop tension. These FRP jackets are usually oriented only in the hoop direction for circular section columns. Hence, the best properties of both of concrete and FRP can be used. Confinement of FRP increases greatly concrete column ductility due to thigh tensile strength of FRP. Thus, both strength and ultimate strain of concrete can be enhanced with FRP confinement [34].

Nowadays, FRP repair is very useful due to the loss of security in order to preserve the structural serviceability. Hence, due to the lack of guidelines for repair with FRP, the need for numerical model to assess different damaged concrete members is feeling. However, analytical and numerical models to assess repaired concrete members are still limited [15]. According to this need, the authors are doing some experiments to evaluate the effects of different pre-damaged levels of cylindrical concrete specimen repaired with CFRP on axial compressive strength of concrete specimen; Figures-2,3. With simulation of behaviour of cylindrical concrete specimens to the concrete columns, the results of this research can be developed from cylindrical specimens to the concrete columns. Hence, the authors are going to investigate stress- strain curves and compare them for different pre-damaged levels of cylindrical concrete specimens.

Figure 2: Fully wrapping of CFRP to repair pre-damaged concrete specimen

Figure 3: CFRP rupture after compressive test

Basically, two parts of damage are considered in repair based on small and large amount of damage. The large amount of damage is considered as defect which is shown in Figure-4.

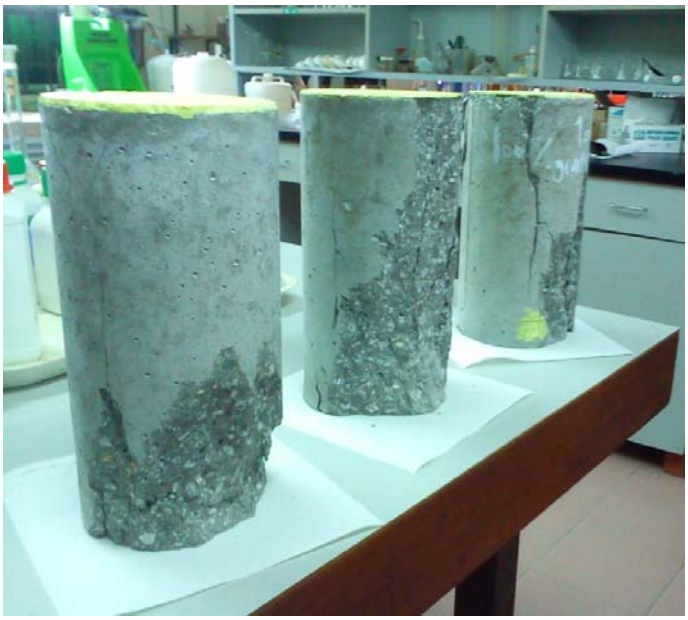

Figure 4. Pre-defected concrete specimens

For repair of defected concrete members, repair mortar must be used before wrapping with FRP. To repair defected parts of concrete members, ASTM C 928-05 has some specifications about rapid repairs for structure materials that include organic compounds [35].

9.0 CONCLUSION

According to this review, lack of knowledge in some parts of this topic has emerged which is described in below.

- For repaired concrete structures, experimental results are not available in terms of different types of damaged.
- There is a need for numerical models for different types of damaged concrete structures to assess strength of repaired concrete members.
- In terms of fire resistance for repaired concrete structures, there are still some gaps about experimental results.
- There is no numerical model to assess repaired concrete members in terms of fire resistance.

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