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Properties of FRP Materials for Strengthening

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Abstract

FRP (Fiber Reinforced Polymers) material is a type of composite material that is increasingly used in the construction industry in recent years. Due to their light weight, high tensile strength, and corrosion resistance and easy to implementation makes these material preferred solutions for strengthening method of reinforced concrete structural elements. In this study it is aimed to discuss advantages of FRP usage as a composite material. It is noted that the mechanical properties of these materials shows a useful behavior for strengthened theoretically to satisfy safe cross-section with FRP materials.

Keywords: *Concrete, Strengthening, FRP, Codes.*

1. Introduction

Strengthening of reinforced concrete structures and components is necessary for many reasons as earthquakes, inadequate strength-strain properties etc. In addition to traditional strengthening methods such as externally-bonded steel plates, jacketing etc, advanced composite materials has became widespread in the strengthening of reinforced concrete (RC) structures. Especially, usage of fiber reinforced polymers (FRP) materials for strengthening has rapidly increased in recent years. Due to their lightweight, high strength, resistance to corrosion, speed and ease of application and formed on site into different shapes can be made them preferences. The composite materials (FRP) applications are used for strengthening of reinforced concrete structures instead of classical method. The benefits of this material externally bonded FRP sheets and strips are currently the most commonly used techniques for strengthening in concrete structures. Table 1 shows typical strength and stiffness values of some strengthening materials. (Piggott, M. 2002)

Table 1. Typical strength and stiffness values for materials used in retrofitting

Material	Tensile strength (MPa)	Modulus of elasticity (GPa)	Density (kg/m3)	Modulus of elasticity to density ratio (Mm^2/s^2)
Carbon	2200-5600	240-830	1800-2200	130-380
Aramid	2400-3600	130-160	1400-1500	90-110
Glass	3400-4800	70-90	2200-2500	31-33
Epoxy	60	2.5	1100-1400	1.8-2.3
CFRP	1500-3700	160-540	1400-1700	110-320
Steel	280-1900	190-210	7900	24-27

From the Table it is noted that the mechanical properties of Carbon Fiber Reinforced Polymers (CFRP) shows the advantage of these material. On the other hand it is observed that the design-oriented stress-strain model for FRP-confined concrete in rectangular columns has a great importance for concrete uniformly-confined with FRP based on test results of circular concrete specimens [1-4]. The studies proposed a new design-oriented stress–strain model for concrete confined by FRP wraps with fibers only or predominantly in the hoop direction based on interpretation of existing test data and observations. However this model reduces directly to idealized stress–strain curves in existing design codes for unconfined concrete. Whereas the compressive behavior up to failure of short concrete members reinforced with fiber reinforced plastic (FRP) were investigated for rectangular cross-sections analyzed by means of a simplified elastic model. A theoretical model for prediction the maximum strength and strain capacities of short compressed column externally wrapped with FRP sheets with rectangular cross sections and sharp or round corners were analyzed.

A finite element analyses were performed to investigate the behavior of square reinforced concrete (RC) columns strengthened by fiber reinforced polymer (FRP) sheet confinement [5]. The study focuses on the contribution of FRP confinement in prevention of longitudinal bar bucklings in cases of inadequate stirrup spacing. The analysis is presented that includes low concrete strength columns with different qualities of steel reinforcement. The results indicate that adequate FRP confinement can provide the restrictive mechanism to resist buckling of longitudinal steel reinforcement, while the lower the yield stress of bars, the lower the gain in strength of FRP confined columns and the lower the strain ductility achieved.

2. Strengthening Techniques for Reinforced Concrete Structures

The main purpose of repairing is to bring back the function of the deteriorated or damaged components of non-structural elements. whereas the theory of strengthening can be defined as the process of enhancing capacity of damaged components of structural concrete to its original design capacity, or an improving over the original strength of structure. Reinforced concrete structures require strengthening due to many reasons. For reinforced concrete buildings some of them can be listed as follows;
- earthquake hazards
- accidents ; such as collisions, fire, explosions
- corrosion of reinforcements
- changes in design parameters or new design standards,
- incorrect calculations and applications of project
- the use of unsuitable materials
- inadequate lateral reinforcement
- changing the usage of buildings (excessive loading)
- additional storey
- poor workmanship

For such structural hazards common strengthening methods are known as concrete jackets, steel jacketing, externally bonded steel plates, external retrofitting and post-tensioning. The most important step in retrofitting is the selection of an suitable interference technique based on type of the structural element. According to JSCE, 1999 [6]; retrofitting of structures shall flowed as follows:

- Identify the performance requirements for the existing structure to be retrofitted and draft an overall plan from inspection through selection of retrofitting method, design of retrofitting structure and implementation of retrofitting work.
- Inspect the existing structure to be retrofitted.
- Based on the results of the inspection, evaluate the performance of the structure and verify that it fulfills performance requirements.
- If the structure does not fulfill performance requirements, and if continued use of the structure through retrofitting is desired, proceed with design of the retrofitting structure.
- Select an appropriate retrofitting method and establish the materials to be used, structural specifications and construction method.
- Evaluate the performance of the structure after retrofitting and verify that it will fulfill performance requirements.
- If it is determined that the retrofitting structure will be capable of fulfilling performance requirements with the selected retrofitting and construction methods, implement the retrofitting work. ’

3. Properties of FRP as a Composite Material

Composite materials can be defined as materials system combined of two or more micro- or macro-component that differ in form and chemical combination and which are fundamentally insoluble in each other. Usage of composite materials has a great importance in many engineering areas such as automotive industry, construction industry, manufacturing industry and new technology products. The purpose of the creating composite materials is to produce superior properties of a new material the production than existing components. In modern materials engineering, composite usually refers to a "matrix" material that is reinforced with fibers [7].

3.1. Classification of Composite Materials

Composite Materials generally have been classified in Metal Matrix Composites (MMC) or Ceramic Matrix Composites (CMC) or Polymer Matrix Composites (PMC) forms with the type of Fiber- reinforced, Particulate or Laminar Composites. The composites in most cases are useful materials. in some cases the negative properties of such materials should be well defined. The general properties of such materials is shown in Table 2

Table 2 .Advantages and Disadvantages of Composite Materials

Advantages of Composite Materials	Disadvantages of Composite Materials
• High strength to weight ratio • High stiffness to weight ratio. • Air condition,corosion and chemicals resistance • Lightweight, • High workability, • Easy formability • Low transport cost due to lightweight • High fatigue and impact strength • Low heat conductivity • Electrical insulation and conductivity	• High manufacturing costs • Brittle, not ductile failure • Materials require refrigerated transport and storage and have limited shelf lives • Composites must be completely cleaned of all contamination before repair. • Composites must be dried before repair because all resin matrices and some fibers absorbmoisture. • Repair at the original cure temperature requires tooling and pressure.

Composite materials are mostly classified in fiber or matrix phases as shown in Fig. 1.

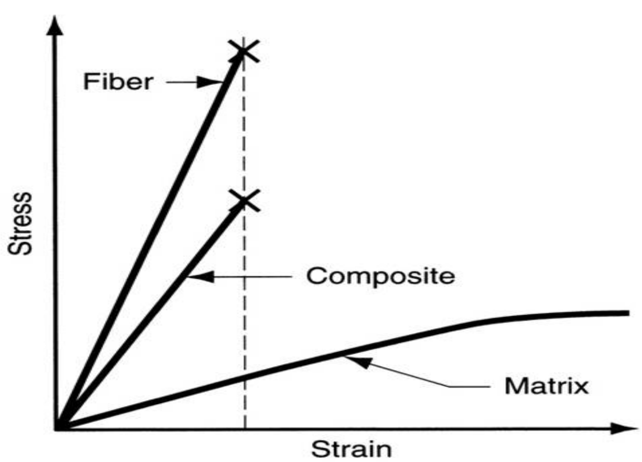

Fig 1. Stress Strain Diagram for Composite Phases

3.1.1 Fibers

Fibers are the effective reinforcements of material, as they satisfy the required conditions and transfer strength to the matrix constituent influencing and enhancing their properties. The performance of a fiber composite can be evaluated by its length, shape, orientation, composition of the fibers and the mechanical properties of the matrix [8]. The main fiber types used in civil engineering are Carbon fibers (CFRP),Glass (GFRP) and Aramid (AFRP). The mechanical properties of the fibers are tabulated in Table 3. On the other hand the stress-strain behavior of such material examples illustrated in Fig.2.

Table 3. Mechanical properties of Fiber Types

Material	Specific gravity (gr/cm^3)	Tensile Strength (N/mm^2)	Modulus of elasticity (N/mm^2)
Glass Fiber	2.54	2410	70000
Carbon Fiber	1.75	3100	220000
Kevlar Fiber	1.46	3600	124000

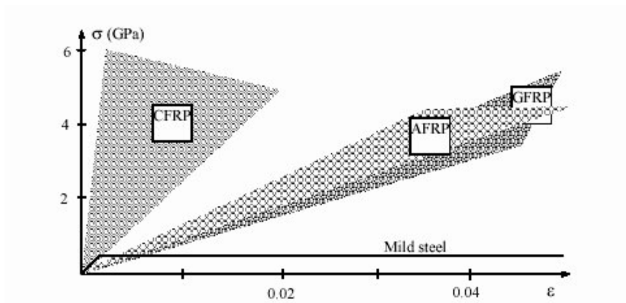

Fig. 2. Uniaxial tension stress-strain diagrams for different unidirectional FRPs and steel. CFRP = carbon FRP, AFRP = aramid FRP, GFRP = glass FRP [9].

The above figure and table represent to summarize the mechanical behavior of the fiber types in uniaxial tension tests.

Carbon Fibers (CFRP): Carbon fibers are anisotropic in nature Carbon fiber, shown in Fig. 3, is produced at 1300ºC. High strength, excellent creep level, resistance to chemical effects, low conductivity, low density and high elastic modulus are the advantages of carbon fibers. The weak sides of carbon fibers are being expensive and anisotropic materials with low compressive strength.

Fig 3. Typical Carbon fibers (CFRP)

Glass Fibers (GFRP): Glass fibers, typical form shown in Fig. 4, are isotropic in nature and most widely used filament. Common types of glass fibers are E-Glass, S-Glass and C-Glass. The characteristic properties of glass fibers are high strength, low cost with good water resistance and resistance to chemicals .

Fig 4. Typical Glass fibers (GFRP)

Aramid Fibers (AFRP) : Aramid fibers widespread known as a Kevlar fiber in the markets as shown in Fig. 5. The structure of Aramid fiber is anisotropic in nature and usually yellow in colors. Aramid fibers are more expensive than glass moderate stiffness, good in tension applications (Cables and tendons) but lower strength in compression. Aramids have high tensile strength, high stiffness, high modulus and low weigh and density. Impact-resistant structures have been usually produced these materials. There are five classes of Kevlar with the different engineering properties Kevlar-29,, Kevlar-49, Kevlar-100, Kevlar-119, Kevlar-129

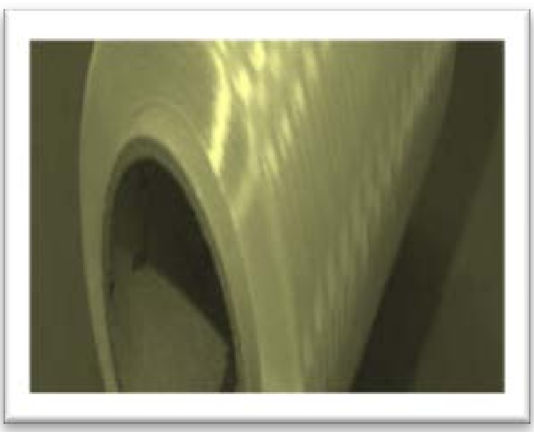

Fig 5. Typical Aramid fibers (AFRP)

In general the mechanical properties of FRP vary with the type and orientation of the reinforcing fibers[10]. Fibers can be oriented in Continuous Form (Continuous and aligned fibers are generally long and straight also fibers distributed parallel to each other) or in Woven Form (Fibers come in cloth form and provide multidirectional strength) or Chopped Form (fibers are short and generally randomly and discontinuous arranged called fiberglass) as shown in Fig. 6.

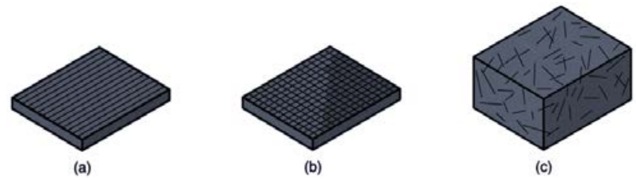

Fig 6. Fiber oriantation in a) continuous b)woven and c) chopped form

3.1.2. Matrix material

Matrices, the second major component of the composite material can be classified as shown in Fig. 7. Selection of the suitable matrix affects the efficiency of the required success in fibers. The main purpose of the matrix is to hold the fibers together, transfers loads to the fibers and protects the fibers from external influences.

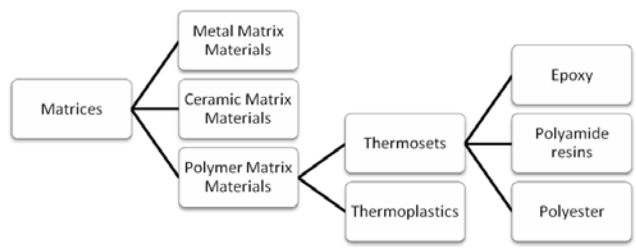

Fig 7.Clasification of Matrix Material

The material properties of moisture and dewatering should also be taken into consideration for the choice of matrix. Shear stiffness, longitudinal compressive strength, strain, failure, fatigue, impact is also very important features. The transverse modulus and strength, the shear properties and the properties in compression are the mechanical properties of the composites which are a strong influence on the matrix. Physical and chemical characteristics of the matrix such as melting or curing temperature, viscosity and reactivity with fibers influence the choice of the fabrication process. Properties of matrices can be summarized as follows [11];

- Reduced moisture absorption
- Low shrinkage and low coefficient of thermal expansion
- Good flow characteristics
- Reasonable strength, modulus and elongation
- Must be elastic to transfer load to fibers
- Strength at elevated temperature
- Low temperature capability
- Excellent chemical resistance
- Should be ease of process into the final composite shape
- Dimensional stability

3.2. Adhesives

The purpose of the adhesive is to attach the composites to concrete surface, so that to provide a shear load path. The most common type of structural adhesives are Epoxy and Polyester , which are the polymer matrix materials (Polymeric matrix) shown in fig 3.7 .Properties of Epoxy and Polyester adhesives are shown in table 3.4

Table .4. Properties of Epoxy and Polyester Adhesives

Properties of Epoxy Adhesives	Properties of Polyester Adhesives
• High cost	• Low cost
• Good electrical properties	• Good mechanical strength
• High bond strength and flexibility	• Good electrical properties
• High temperature resistance,	• Low viscosity and versatility
• Low shrinkage during curing	• Good heat resistance
• Better adhesion between fibre and matrix	• Cold and hot molding
• Resistance to chemicals , solvents and water	• Curing temperature is 120°C
• Resistance to creep and fatigue	• Good handling properties
• Limited temperature application range upto 175°C	• Poor chemical resistance
• Moisture absorption affecting dimensional properties	• High curing shrinkage
• High thermal coefficient of expansion	• Fair weatherability
• Extremely harmful to the skin	

Conclusions

Fiber-reinforced polymer (FRP) as a composite material consisting of high tensile-strength fibers bonded to the surface using an epoxy resin or embedded in a matrix of polymer resin is a powerful strengthening method for concrete structures. In the last decade, the use such polymers as reinforcement are rapidly extended to wide applications for structural strengthening in construction engineering. Therefore the developments in such composite materials have a great importance for engineers. It is noted that the achievement of FRP strengthening is highly dependent on the installation of the FRP material. Laboratory tests to check laminate strength and pull tests to check the bond with the surface items should be considered during construction to help ensure successful FRP applications.

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