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Flexural strengthening of reinforced normal strength concrete beamsby using different techniques: A critical review

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Abstract: *The use ofFiber-reinforced polymerscomposite materials in repairing and strengthening damaged structural parts,especially those made of reinforced concrete, is wide spreads. However, each FRP composite that used in the strengthening of beams must carefullychose, there are many techniques used in the strengthening of beams such as externally bonded reinforcement (EBR) and near-surface mounted (NSM) and FRP composite applied to the surface of the beam in different shape and forms such as U-anchorage, a bottom face, strips, plates, laminates, and sheets. This paper highlights the effect of different FRP composite,and strengthening techniques on the flexural strength of the reinforced concrete beams. The results showed that the flexural strength of reinforced concrete beams improved up to170.2 %, 53%,50 %, and 45.1 % due to strengthening by CFRP composites, aramid FRP composite,GFRP composite, graphite FRP composite, and prestressed CFRP,respectively. Moreover, the jacketing techniques with two vertical and two horizontal of the CFRP plate are the most suitable way for flexural strengthening, which improves up to 235%.*

Keywords:*Aramid, Carbon fiber reinforced polymer,Flexural strengthening, Fiber-reinforced polymer, Glass Fiber-reinforced polymer, Near surface-mounted*

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I. INTRODUCTION

1.1.General

The number of structures in the world continues to increase, as do theiraverage age. The need for increased maintenance is inevitable. Strengthening concrete structures should think of once the current structure deteriorates or any alteration to that structure should create because the existed structure or building may lose its purpose.

Complete replacement is probably going to become an increasing budget burden. It isa waste of natural resources if upgrading could be a workable alternative, theway within which strengthening technique could be useful and help the structure to gain better strength to resist different kinds of failure and deterioration that take place in the concrete [1,2].

The strengthening of any structure is required when there is an increase in load due to increasing live load, wheel load, and installation of heavyweight vibration and machines; also when the structure damaged due to physical deteriorations such as fire damage,overloading, abrasion, spalling, impact loads, corroding of steel reinforcementusually results in a reduction in load-carrying capacityand cracking of the concrete. Due to the decreasing in the cross-section area of the reinforcement, the main factors for corrosion are chloride attack, carbonation of concrete cover and combination of these two mechanisms; in addition when the plan of the structure changed due decreasing the number of beams, walls, columns and making opens in the slabs[3].

Furthermore, when there are errors in construction and designing of the structure, such as inadequate dimension in plans and insufficient reinforcing steel in the designing process of the structure [3].

The other factors are Damages due to deterioration of the concrete matrix - there are a number of effective mechanisms, some of them associated with the constituents of the concrete and some

of them caused by environmental factors, in many instances the tools are sophisticated, the mechanisms which are encountered and include Alkali-aggregate reactions (AAR), Delayed Ettringite formation,Sulfate attack,Freeze-thaw cycles,Microbiologicalalattack [3].

1.2 History of FRP in civil engineering

The use of Fiber-reinforced polymers FRP in concrete structures as a strengthening material has grown very fast compared with other materials [1]. In the middle of 1950's FRP was used in the united states, FRP was available in the form of bars, grids, sheets, plates, and laminates, as shown in Figure1 [4].

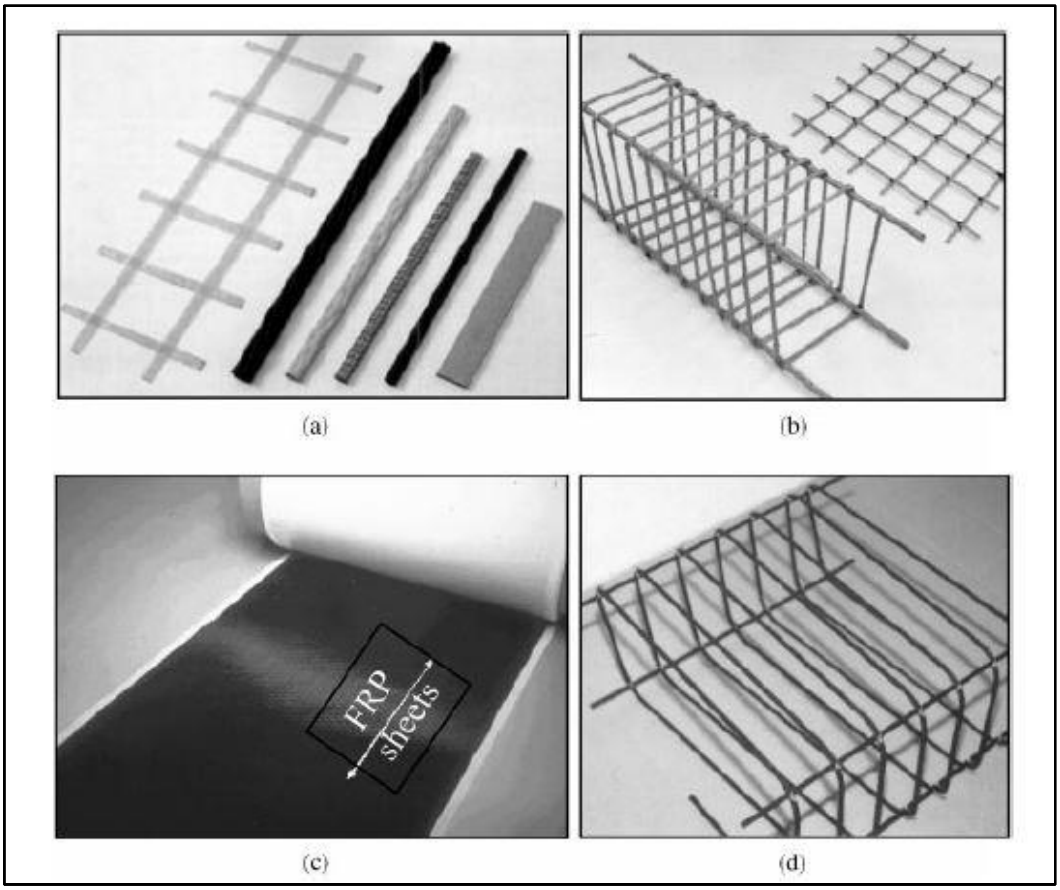

Figure1: Forms of FRP: a) bars,b) grids, c) sheets,d) cage.

Fiber-reinforced polymer (FRP) forthe first time utilized in the commercial applications at the end of 1970's, in 1984, carbon fiber reinforced polymer (CFRP) was used by Meierfor the structural strengthening and repair[4].

In Germany the world's first prestressed glass fiber reinforced polymer was constructed in 1986, since then in the construction of bridges in the United States, Japan, and Europe, FRP used.

The pioneer in this field of application was the California transportation department inthe UnitedStates for using carbon fiber reinforced polymer by seismically renovating bridge columns in the early 1990's [3].

There was a dramatic change in advanced strengthening techniques in 1987 by Meier when he removed an external steel plate that they under the effect of corrosion and changed the steel plate by reinforcing fibers of carbon polymer (CFRP).

1.3 FRP composite

FRP composite is a combination of a load-bearing constituent that mainly consists of fibers and polymerized matrix resin is called FRP composite,the matrix resin is used for binding and protecting the Fiber from humidity, high temperature, and chemical attack and also facilitate load transfer through the fibers; otherwise, the matrixresin ensures the orientation and directional stability of the embedded fibers.

FRP composites have variations in the properties that depend on the production and fabrication process [5,6].

Glass, carbon, and aramid reinforcingfibers most commonly used fibers, also nowadays basalt fibers are commercially available type fibers that are produced from volcanic rocks and have a good chemical and thermal resistance, FRP composites promoted as twenty-first-century materials due to their superior corrosion resistance, glorious thermos mechanical properties, and high strength-to-weight ratio. FRP composites also are 'greener' in terms of embodied energy than standard materials such as concrete and steel [7,8].

1.4.Properties of FRP composites

FRP composites have a high strength to weight ratio;a minimum tensile strength that glass fibers can carry it is between 2400–3500 MPa, the amount of this strength of the composite will reduce and depends on the ratio reinforcing fibers to resinFigure 2 shows the relationship of stress-strain FRP materials. However, it would still be significantly higher than that of most steel [2].

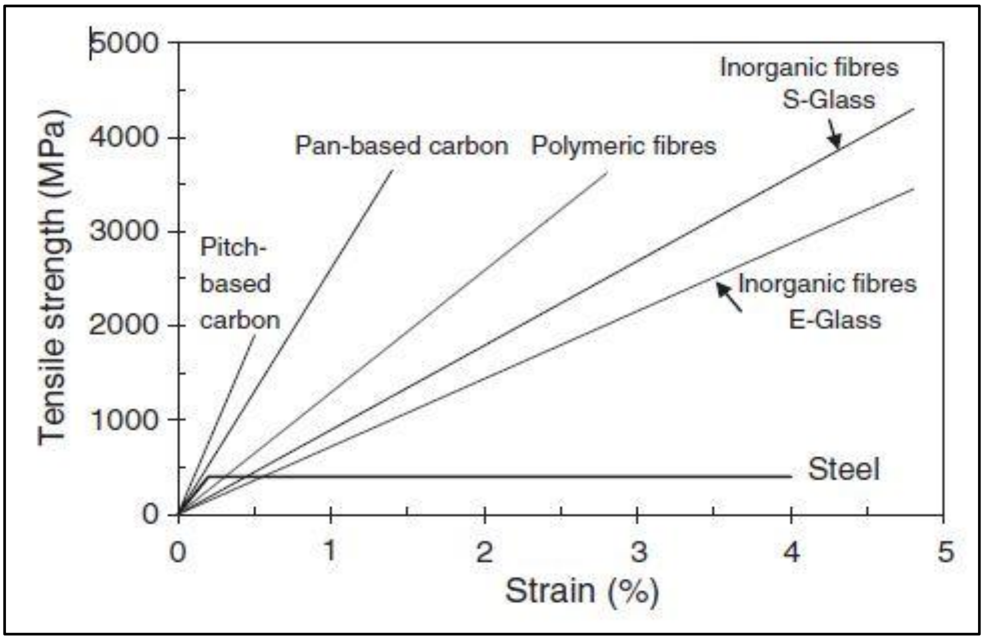

Figure 2: Stress-strain relationship of FRP materials

The properties of FRP may tailor as desired by replacing the direction and amount of fibers; Fabricators have great flexibility in their selection of materials, fabricators chose the most acceptable reinforcing fibers such as (carbon, glass, aramid,etc.), and additionally arrangement (chopped, woven or sewed materials of varied geometries).

The density of concrete is 2300 kg/m^{3}glass fiber-reinforced polymer composite (GFRP) is typically about 1800 kg/m^3, while the density of steel is about 7850 kg/m^3. Thus, FRP materials require less heavy lifting equipment and formwork (scaffolding) than conventional materials and can handle by a smaller workforce [8].

FRP composites have resistance against water, salt, and different chemicals, and oil has no effect on them and is unaffected by various significant hydrocarbons; as a result, they have little maintenance as compared to standard materials.

FRP composites have more cost comparing with conventional materials when the comparison based on the weight of each material [3].

FRP composites have a negative property such as they have a low coefficient of thermal expansion, and this problem begins when the FRP is used in conjunction with conventional material, to eliminate this problem a careful design must do. The properties of resin depending on the temperature, for example, when the temperature has decreased, the strength of the composite is increased, and this effect on the degree of the brittleness of the resin and the resin became more brittle [4,6].Besides, when the temperature increased, the resin is exposed to fire the surface of the resin ids burns, and a layer like tar is produced that protects the underneath fibers, and this led to postponing the time of the failure of FRP composite. There is also an important property of FRP composite which is stiffness (measured as modulus of elasticity), the steel has 200 kN/mm^2 comparing with carbon fiber reinforced polymer (CFRP)has a modulus of elasticity of up to 300 kN/mm^2 and this amount is higher than steel. In comparison, the glass fiber reinforced polymer (GFRP) has a lower range of elastic modulus of 72-87 kN/mm^2. The stiffness of GFRP is driving GFRP design instead of its strength [7].

II. FLEXURAL STRENGTHENING OF REINFORCED CONCRETE BEAMS

2.1. Flexural strengthening of reinforced lightweight polystyrene aggregate concrete beams with near-surface mounted GFRP bars.

Tang et al.(2006) studied the flexural strengthening by GFRP bars in lightweight polystyrene concrete. Inthis research, 12 samples of the reinforced concrete beam cast and tested. Two specimens were normal strength concrete with primary flexural reinforcement varied and consist of steel and GFRP. Also, five beams were lightweight polystyrene concrete with (20 and 40 %) content of polystyrene strengthened with GFRP bars by the technique of NSM, and the primary reinforcement of these five samples were steel and GFRP. Besides, the remained five beams tested, and the type of concrete was normal strength concrete and lightweight polystyrene concrete and did not have strengthening, and the primary reinforcement was steel GFRP bars.

The results showed that beams with NSMstrengthened with GFRP bars with the polystyrene ratio of 20% have an increase in the amount of the ultimate flexural strength from 23 % to 53% as they compared with normal strength concrete.

2.2 Flexural strengthening of fire-damaged reinforcedconcrete continuous t-beams with CFRP sheets

Kai et al. (2011) studied the flexural strengthening of fire-damaged reinforced concrete beams with CFRP sheets. In this research, seven reinforced concrete T-beam cast and tested. One beam was controlled sample and not strengthened with CFRP, and three samples were strengthened with CFRP sheets in the bottom of mid-span and top CFRP over the central support after their exposure to fire for 60 minutes. Besides, the remain three samples strengthened with CFRP sheets in the bottom of the mid-span and top CFRP over the central support after their exposure to 75 minutes of direct fire. The results showed that the beams that exposed to fire for 60 minutes and strengthened with CFRP sheets have the maximum loading capacity, and failure occurred when CFRP sheets ruptured in tension.

2.3 Flexural strengthening of reinforced concrete beams with prestressed CFRP plates

Deng et al. (2011) studied the flexural strengthening of reinforced concrete beams with prestressed CFRP plates. In this research,four normal strength concrete beams reinforced with 2Ø10mm and 2Ø20mm in compression and tension zones. One of the beams is a controlled sample (non-strengthened beam), and one beam strengthened with a conventional CFRP plate, and the other two samples strengthened with (20 and 40 %)of prestressing of CFRP plates, respectively.Results showed that there is an increase in the ultimate moment capacity of the beams, which strengthened by prestressed CFRP platesfrom 17 % to 35 %, compared to the beams which strengthened with non-pre-stressed CFRP plate and the controlled beam. And then, the failure mode of reinforced beams byprestressed CFRP plate was the crushing of concrete.

2.4Flexural behavior of reinforced concrete beams externally strengthened with CFRP sheets bonded with an inorganic matrix.

Toutanji et al. (2006) investigated the effect of CFRP sheets bonded with an inorganic matrix on the flexural behavior of reinforced concrete beams. Inorganic epoxy that used in this researchproduced bymixing water-based activatorwith aluminosilicate powder, and this type of epoxy has good workability, higher fire resistance, andno emission of odors and toxic and can be named as environmentally friendly material. In this research, eight reinforced normal strength concrete beams were cast and tested with the primary reinforcement consists of 2#2 and 2#3 at the compression and tension zones, respectively. One of the samplescontrolled beams, and the other seven beams strengthened with CFRP sheets with 3,4,5 and 6 layers of CFRP sheets, which has tensile strength 660 MPa.The results showed that the ultimate moment capacity of beams increased with increasing the CFRP layers by 170.2% compared with the controlled beams, and the mode of failure for 5 and 6 layers of CFRP was delamination of CFRP plates.

2.5Flexural strengthening of concrete beams using CFRP, GFRP, and hybrid FRP sheets

Attari et al. (2012) studied the flexural strengthening of reinforced concrete beams by CFRP, GFRP, and hybrid FRP sheets. Hybrid FRP composite has a tensile strength of 400 MPa has nearly equal strength with CFRP composite with tensile strength 403 MPa and more significant than the tensile strength of GFRP composite with 325 MPa.

In this research,seven normal strength concrete beams were cast and tested with the primary reinforcement of 2Ø10 mm and 2Ø8 mm in tension and compression zones. The beams divided into four groups, the first one controlled beam, the second group consists of strengthened beams with two layers of CFRP, GFRP by jacketing technique, the third group contained strengthened beams by hybrid FRP composites by jacketing technique, and the four groups contain beams strengthened in the bottom face with three layers of HFRP composite.

The results showed that maximum loading capacity could see from the beam that contains two layers of GFRP and CFRP composite with 0° oriented by the method of jacketing and the results illustrated that the jacketing (U-anchorage) technique was very effective in increasing the ultimate moment capacity due to internal forces redistributed through the greater deformations of the beam specimen.

2.6Strengthening of Concrete Beams Using Innovative Ductile Fiber-Reinforced Polymer Fabric

Grace et al. (2002) studied the effect of innovative ductile fiber-reinforced polymer fabric on flexural strength in reinforced concrete beams. In this research, thirteennormal strength concrete beam were cast andtested with the primary reinforcement 2Ø16 mm and 2 Ø10mm in tension and compression zones. The results showed that the maximum loading capacity could see from the beam that strengthened by jacketing method with a hybrid FRP composite with a thickness of 1.5 mm.

2.7 Strengthening reinforced concrete beams using fiber-reinforced polymer (FRP) Laminates

Grace et al. (2002) studied the influence of FRP strengthening of reinforced concrete beams. The beams in this test strengthened after the cracking load reached. The results showed that the beam, which strengthened by jacketing with two vertical and two horizontal CFRP plates, has the ultimate loading capacity by 2.35 times higher than the controlled beam.

2.8Flexural strengthening of concrete beams using externally bonded composite materials

Chajes et al. (1994) studied the strengthening of reinforced concrete beams for flexure using externally bonded composite materials. Fourteen beams tested in this research, and 12 of them were under reinforced, and two of them reinforced with primary reinforcement 2#3 in tension and compression zone. The results showed that the range in increasing flexural capacity of strengthened beams was 45%,45.6%, and 53.2 % for Graphite, Glass, and aramid FRP composite comparing with the controlled beam, respectively.

2.9 Reinforced concrete beams strengthened with externally bondednatural flax FRP plates

Huang et al. (2016) studied the effect of externally bonded natural flax FRP plates on the flexural strength of reinforced concrete beams. In this research, the number of layers and the arrangement of FRP governed as an experimental parameter. The results showed that there is an increase in the ultimate load capacity of beams with increasing the number of layers of FRP, ranging from 15.5 to 112.2 % compared with controlled beam samples.

2.10. Effects of FRP reinforcement ratio and concrete strengthon flexural behavior of concrete beams

Barros et al. (2007) studied the impact of the FRP reinforcement ratio on the flexural behavior of reinforced concrete beams. The number of FRP layers, the arrangement of FRP, and techniques of strengthening were studied. The results showed that the NSM technique was the most effective in increasing the flexural strength of beams. Still, the efficiency of near-surface mounted (NSM), and the externally bonded reinforcement (EBR) decreased when the equivalent longitudinal reinforcement ratio increased.

III. RESULTS AND DISCUSSIONS

The primary materials used for flexural strengthening are prestressed CFRP, Graphite FRP composite, GFRP composite, and Aramid FRP composite. The most suitable material for flexural strengthening is Aramid FRP composite, as shown in Figure 3. While the jacketing technique for flexural strengthening with two vertical and horizontal CFRP plates was improved flexural strength of reinforced concrete beams more than the other methods for strengthening such as Near Surface Mounted NSM and Externally Bonded Reinforcement EBR.

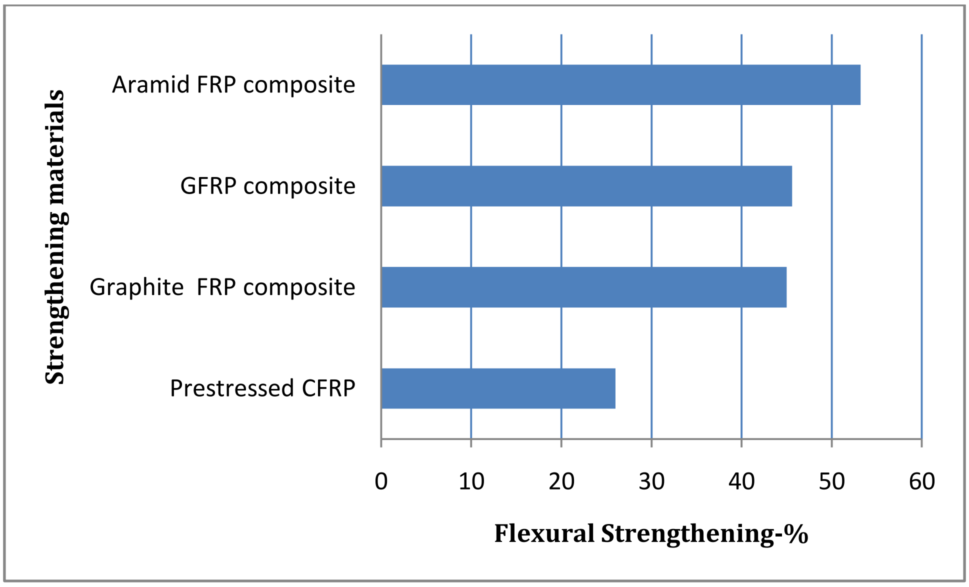

Figure 3: Flexural strengthening percentage of different strengthening materials

IV. CONCLUSION

FRP composite that used in the strengthening of beams must carefully choose, there are many techniques used in the strengthening of beams such as externally bonded reinforcement (EBR) and near-surface mounted (NSM), and FRP composite applied to the surface of the beam in different shape and forms. Therefore, the effect of different FRP composite, epoxy type, and strengthening techniques on the flexural strength of the reinforced concrete beams highlighted in this paper in detail. The following conclusions could drown:

1. The Flexural strengthening by CFRP composites is higher when compared with aramid, glass, graphite FRP composites.
2. The flexural strengthening by prestressed CFRP has enhanced more with increasing the ratio of prestressing.
3. Jacketing and U-anchorage shape of strengthening had a more flexural enhancement compared with strengthening in the bottom face of the beam due to the internal forces redistributed through the more significant deformations of the beam.
4. Flexural strength improved up to 170% by increasing the number of FRP composites layers.
5. Flexural strength for the strengthened beams with near mounted surface (NSM) technique was higher than externally bonded reinforcement technique (EBR). However, the jacketing methods with two vertical and two horizontal of the CFRP plate are the most suitable way for flexural strengthening, which improves up to 235%.
6. Reinforced concrete beams strengthened by a hybrid FRP composite had a higher flexural strength when compared with conventional FRP composites.
7. For fire-damaged beams, the critical factor for increasing the quantity of flexural strength of reinforced concrete beams is the time that the reinforced concrete beam subjected to fire.
8. Tensile strength and type of epoxy influenced the failure mode and flexural strength of strengthened reinforced concrete beams.
9. The patterns of failure for the strengthened beams varied with the kind of FRP composite and the binding materials.
10. The most effective thickness of the hybrid FRP composite is 1.5 mm for flexural strengthening.

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