# The usage of carbon fiber reinforcement polymer and glass fiber reinforcement polymer for retrofit technology building

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**Abstract.** Fiber Reinforcement Polymer has been used as a material technology since the 1970s in Europe. Fiber Reinforcement Polymer can reinforce the structure externally, and used in many types of buildings like beams, columns, and slabs. It has high tensile strength. Fiber Reinforcement Polymer also has high rigidity and strength. The profile of Fiber Reinforcement Polymer is thin and light, installation is simple to conduct. One of Fiber Reinforcement Polymer material is Carbon Fiber Reinforcement Polymer and Glass Fiber Reinforcement Polymer. These materials is tested when it is installed on concrete cylinders, to obtain the comparison of compressive strength CFRP and GFRP. The dimension of concrete is diameter of 15 cm and height of 30 cm. It is amounted to 15 and divided into three groups. The test is performed until it collapsed to obtain maximum load. The results of research using *CFRP* and *GFRP* have shown the significant enhancement in compressive strength. CFRP can increase the compressive strength of 26.89%, and GFRP of 14.89%. For the comparison of two materials, CFRP is more strengthening than GFRP regarding increasing compressive strength. The usage of CFRP and GFRP can increase the loading capacity.

## 1. Introduction

The development of concrete's technology at present has made concrete become a priority as a construction material. Construction of concrete has many advantages, besides the material is very easy to obtain, it has several advantages such as the relatively affordable price, high compressive strength, and easy maintenance, so many buildings are prefer to choose concrete as a construction material.

The selection of materials as construction has made experts create external reinforcements for concrete. The reinforcement are considered as important materials, especially for construction at the recent time that requires everything that is practical, efficient, without reducing the quality of the concrete. The evolution of an external reinforcement has been introduced to a new design for the binding of reinforced concrete columns. One method for enhancing reinforced concrete columns is using FRP (Fiber Reinforcement Polymer) Composites as reinforcement.[11]

The use of FRP as one of the new alternatives in the improvement and strengthening concrete structures, is able to offer repair solutions that are easier in terms of implementation and can be applied by every contractor. Application of strengthening methods with polymer fibers requires proper planning, both in terms of design (behavioral analysis of concrete structures), field conditions (environmental influences) and maintenance of fiber types. This is essential to avoid the repair process so that no failure occurs in the reinforcement system. The use of polymer fibers under an extreme environmental conditions will require a system of protection of the fiber surface from the effects of temperature, chemicals and ultraviolet radiation.[4]

## 2. Literature Review

One of the structural reinforcement materials is Fiber Reinforcement Polymer which can strengthen the structure externally, and is now used in many types of buildings. It is due to the great tensile strength possessed by FRP (Fiber Reinforcement Polymer). Fiber Reinforcement Polymer also has high stiffness and strength. And the installation is very easy to conduct. FRP composites are a promising material in the construction improvement industry. This material may be obtained in the form of sheets in which its application is applied with resin or epoxy. This material has been widely used and applied. The common traditional method is using steel plate material tied with epoxy on a reinforced concrete column structure. But gradually, this technique or method began to shift with the presence of a new material called FRP. With this material reinforcing the structure can result the substantial increases in strength (axial, shear, bending, and torque).[15]

FRP can be made from different materials such as glass, carbon, aramid, boron, and other products. FRP is strong against tensile and has the highest strength along the longitudinal direction. The advantages of using glass materials are affordable, possessing high tensile strength and high chemical reaction, whereas the disadvantages are having low tensile modulus, relatively more dense and sensitive to abrasion. The advantage of using carbon material is the ratio of tensile strength to the heavy weight and tensile modulus to the heavy weight. The advantage of using aramid material is the absence of melting point, good plant integrity level to high temperature.[6]

FRP can increase the strength 25 % of carbon material [11] and can increase 11.86% - 15.25% of glass material.[13] The characteristics of FRP are highly resistant to chloride ions and chemical reactions, also having greater tensile strength than steel but weight only a quarter, moreover, GFRP has low electricity and thermal conductivity.[8]

The advantages of FRP are for strengthening purpose. The addition of FRP on both sides of the block affects the pattern of the crack that occurs. Cracks in the concrete switch/ occur to a position where the GFRP reinforcement does not exist. It makes concrete even more practical.[2]

To obtain the compressive strength of concrete, it needs a concrete cylinder test object with 150 mm diameter and 300 mm high. For the calculation of the thrust strength of cylindrical concrete test object, the following formula can be used;

$$f'c = \frac{P}{A} \tag{1}$$

Note,
$f'c$ = compressive strength of concrete (Mpa)
$P$ = pressure load (N)
$A$ = the cross-sectional area of specimen ($mm^2$)

The elasticity modulus of concrete is the slope of the concrete strain stress curve in linear or even approaching linear conditions. For normal concrete, values may be used is (SNI 03-2847-2002 Section 8.5.1):

$$Ec = 4700\sqrt{f'c} \tag{2}$$

Note,
$f'c$ = compressive strength of concrete (MPa)

To obtain the concrete strain, Hooke law is used:

$$E = \frac{\sigma}{\varepsilon}, then\ \varepsilon = \frac{\sigma}{E} \tag{3}$$

Note,
Ɛ = strain of concrete
E = elasticity modulus of concrete (MPa)
σ = compresive strength of concrete (MPa)

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These are some of the compressive strengths equations expressed by previous researchers on the compressive strength of concrete with FRP (f'cc) by Richart's Model (1928) in (ACI Committee 440.2R, 2008). In principle, the analytical confinement model expresses the relationship between compressive strength and lateral stress arising from confinement. The basic equations describing the relationship can be described as follows:

$$f'cc = f'co + kl.fl \quad (4)$$

Note,
*f'cc* = compressive strength of confined concrete (MPa)
*f'co* = compresive strength of unconfined concrete (MPa)
*fl* = confined strength caused by FRP (MPa)
*k1* = confined factor (*kl* = 1, for the concrete does not use the spiral reinforcement)

For the value of *fl*, is the tensile caused by *FRP* which can be formulated as follows:

$$fl = \frac{Ka.\rho_f.E_f.\varepsilon_{fe}}{2} \quad (5)$$

Note,
$Ka$ = the efficiency factor of the cross section shape (for round shape, $Ka$=1)
$\rho_f$ = the strengthening ratio of FRP
$E_f$ = elasticity modulus of FRP (MPa)
$\varepsilon_{fe}$ = the effective fracture strain (= 0.004 ≤ 0.75 $\varepsilon_{fu}$, $\varepsilon_{fu}$ = ultimate strain of FRP)
For $\rho_f$ it can be formulated as:

$$\rho_f = \frac{4.n.t_f}{h} \quad (6)$$

Note,
h = diameter of coloumn (mm)
*tf* = thickness of FRP (mm)
*n* = number of layers of FRP

Here are some equations by previous researchers on concrete strain with FRP ($\varepsilon_{cc}$) In (ACI Committee 440-2R, 2008)

$$\varepsilon_{cc} = \varepsilon'_c( 1.5 + 12\, K_b \frac{f_l}{f'c} (\frac{\varepsilon_{fe}}{\varepsilon'_c})^{0.45}) \quad (7)$$

Note,
$\varepsilon'_c$ = the strain of concrete (MPa)
$K_b$ = the efficiency factor of the cross section shape (for round shape =1)
$f_l$ = confined strength caused by FRP (MPa)
*f'c* = compresive strength of unconfined concrete (MPa)
$\varepsilon_{fe}$ = the effective fracture strain (= 0.004 ≤ 0.75 $\varepsilon_{fu}$, $\varepsilon_{fu}$ = ultimate strain of FRP)
$\varepsilon'_c$ = the strain of unconfined concrete

## 3. Research Methodology

The method in this study is an experimental study conducted at the Material Laboratory on Faculty of Engineering, University of Sumatera Utara and The Centre of Educators and Teachers Development and Empowerment Laboratory. The test object used in this study is cylinders with diameter size of 15 cm and height of 30 cm with three types of specimens with 5 pieces each.

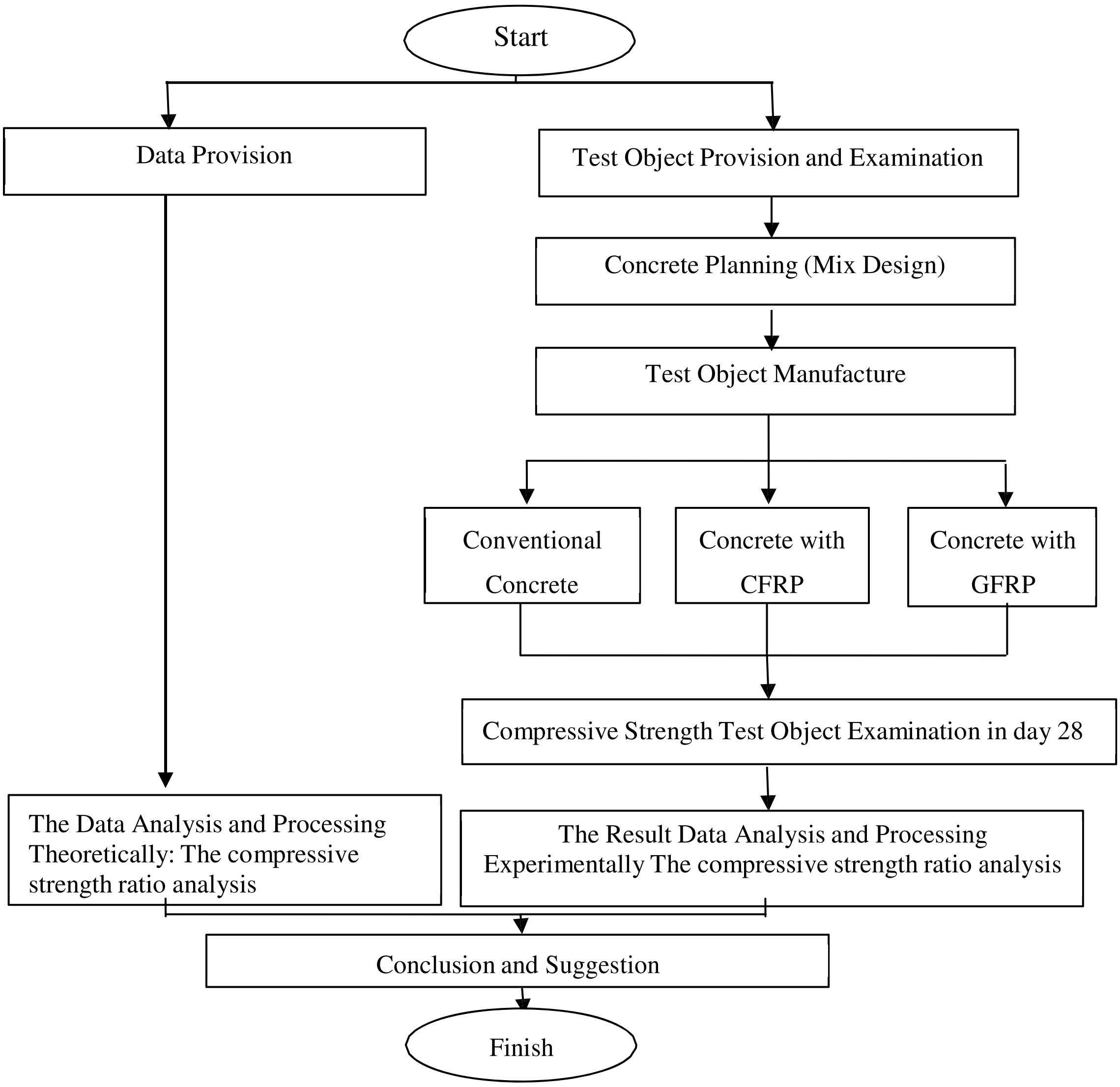



**Figure 1.** Research Methodology Flowchart

The Compressive Test was done by Compression Test Machine at The Centre of Educators and Teachers Development and Empowerment Laboratory as shown in Figure 2 below.

**Figure 2.** Compression Test Machine GOTech U60

The test was conducted to the concrete in day 28 for each concrete variation with 5 pieces each. The variation of concrete can be seen in figure 3 and 4 below.

**Figure 3.** Test Object

**Figure 4.** Test Object in Compression Machine

For the analysis, the analytically was done by the method of ACI Committee 440R-02, 2008 and Richarts Model in section 2, and the experimentally tests were conducted based on SNI 1974: 2011.

## 4. Finding

*Compressive Strength and Strain of Cylindrical Concrete*

Before the testing, it requires an analysis so that the experiment do not fumble, therefore we need the calculation of the compressive and stretching strength of the concrete, the analysis was done by the method of ACI Committee 440R-02, 2008 and Richarts Model.

**Table 1.** The Compressive Strength and Strain of Concrete Analytically

| Test Object | Compressive strength (MPa) | Stretching |
|---|---|---|
| **Conventional Concrete (BK)** | 30 | 0,001 |
| **Concrete with CFRP (BC)** | 54,15 | 0,006 |
| **Concrete with GFRP (BG)** | 35,04 | 0,003 |

Therefore, Based on the result compiled in table above, the chart of Analytical compressive strength can be made as shown in figure 5 below.

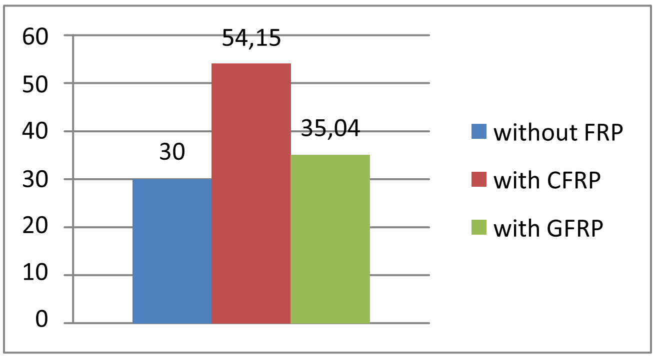



**Figure 5.** The Chart of Analytical Compressive Strength

Therefore, the addition of CFRP increased the compressive strength of concrete by 44.6% due to the large CFRP elasticity modulus, whereas with GFRP, it increased the compressive strength by 14.384%

due to the modulus of elasticity of GFRP is smaller than CFRP. And the strain that occurs < 0.01 so it qualifies the term of ACI Committee 440R-02, 2008.

This test was aimed to find out the value of compressive strength of conventional concrete, concrete with CFRP, and concrete with GFRP, where the cylindrical test object through the process of manufacture and maintenance conducted in the Laboratory of Concrete at University of Sumatera Utara. Tests were performed at day 28. Tests were conducted based on SNI 1974: 2011, How to test the compressive strength of concrete with cylindrical test object. Strong test results are compiled in the table below.

**Table 2.** The Result of Compressive Strength of Concrete Experimentally

| No | Test Object | Age of Concrete (Days) | Weight (kg) | Actual Compressive Mass (kN) | Cross Section Area (cm2) | Actual Compressive Strength (MPa) | Average Compressive Strength (MPa) |
|---|---|---|---|---|---|---|---|
| 1 | BK 1 | 28 | 12.560 | 767.129 | 176.625 | 43.433 | |
| 2 | BK 2 | 28 | 12.567 | 721.056 | 176.625 | 40.824 | |
| 3 | BK 3 | 28 | 12.578 | 625.303 | 176.625 | 35.403 | 38.983 |
| 4 | BK 4 | 28 | 12.573 | 683.885 | 176.625 | 38.720 | |
| 5 | BK 5 | 28 | 12.550 | 645.300 | 176.625 | 36.535 | |
| 6 | BC 1 | 28 | 12.680 | 869.571 | 176.625 | 49.233 | |
| 7 | BC 2 | 28 | 12.677 | 953.195 | 176.625 | 53.967 | |
| 8 | BC 3 | 28 | 12.679 | 989.494 | 176.625 | 56.022 | 53.32 |
| 9 | BC 4 | 28 | 12.687 | 946.582 | 176.625 | 53.593 | |
| 10 | BC 5 | 28 | 12.678 | 950.135 | 176.625 | 53.794 | |

| No | Test Object | Age of Concrete (Days) | Weight (kg) | Actual Compressive Mass (kN) | Cross Section Area (cm2) | Actual Compressive Strength (MPa) | Average Compressive Strength (MPa) |
|---|---|---|---|---|---|---|---|
| 11 | BG 1 | 28 | 12.550 | 928.736 | 176.625 | 43.643 | |
| 12 | BG 2 | 28 | 12.680 | 817.173 | 176.625 | 38.401 | |
| 13 | BG 3 | 28 | 12.660 | 657.688 | 176.625 | 30.906 | 45.803 |
| 14 | BG 4 | 28 | 12.676 | 823.394 | 176.625 | 38.693 | |
| 15 | BG 5 | 28 | 12.678 | 817.990 | 176.625 | 38.439 | |

The result of the compressive strength shown in the table above is the result of the compressive strength that has been multiplied by the shape factor for a normal cylinder with a diameter of 15 cm and a height of 30 cm. Shape factor for normal cylindrical test specimen is 1 in accordance with SNI 1974: 2011

**Table 3.** The Strain Results of Concrete Experimentally

| No | Test Object | Age of Concrete (Days) | Stretch (%) | Average Stretch (%) |
|---|---|---|---|---|
| 1 | BK 1 | 28 | 0.0086 | |
| 2 | BK 2 | 28 | 0.007 | |
| 3 | BK 3 | 28 | 0.013 | 0.00932 |
| 4 | BK 4 | 28 | 0.012 | |
| 5 | BK 5 | 28 | 0.006 | |
| 6 | BC 1 | 28 | 0.0063 | |
| 7 | BC 2 | 28 | 0.00626 | |
| 8 | BC 3 | 28 | 0.0096 | 0.0065 |
| 9 | BC 4 | 28 | 0.0057 | |
| 10 | BC 5 | 28 | 0.0045 | |
| 11 | BG 1 | 28 | 0.0026 | |
| 12 | BG 2 | 28 | 0.0016 | |
| 13 | BG 3 | 28 | 0.001 | 0.002 |
| 14 | BG 4 | 28 | 0.0022 | |
| 15 | BG 5 | 28 | 0.0021 | |

Based on the table above, it can be seen that with the use of FRP, the compressive strength of concrete has increased with CFRP and GFRP as well.

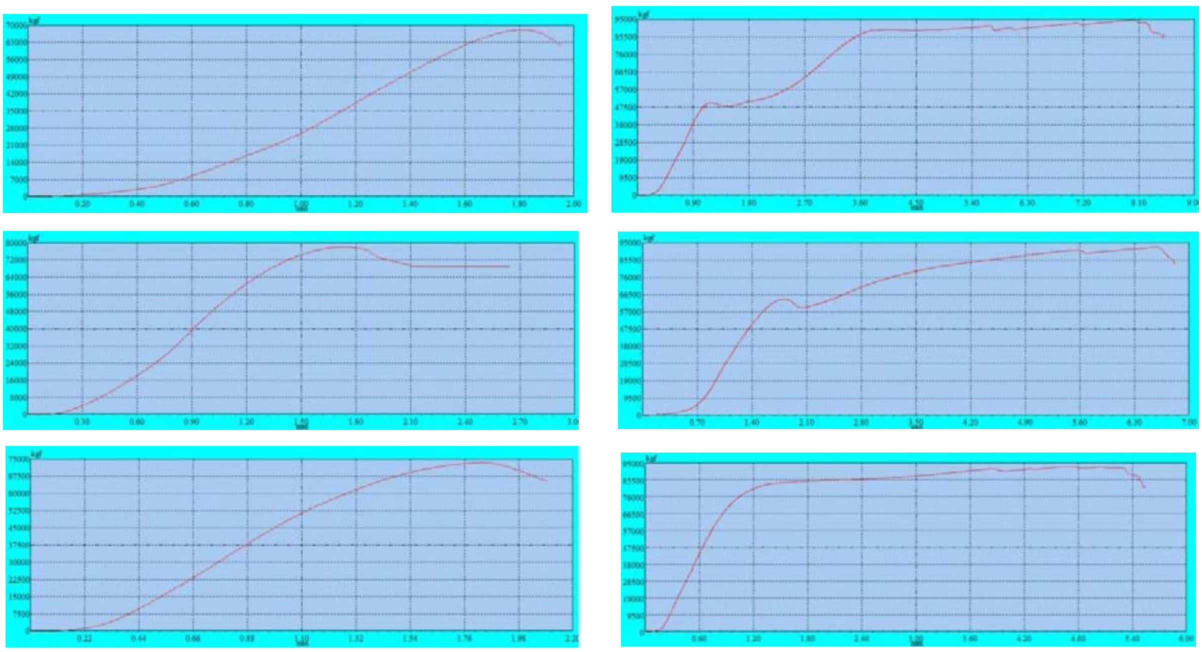


**Figure 6.** The Graph of The Relationship Between Loading and Vertical Deformation for concrete with *CFRP*

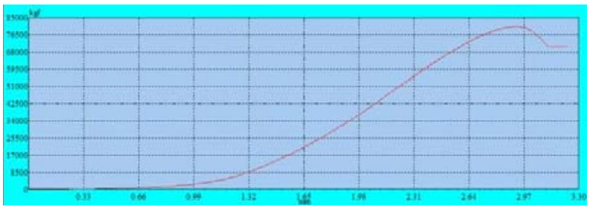
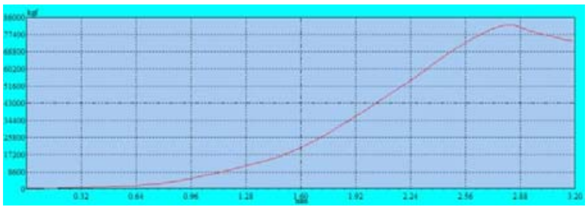


**Figure 7.** The Graph of The Relationship Between Loading and Vertical Deformation for Conventional Concrete



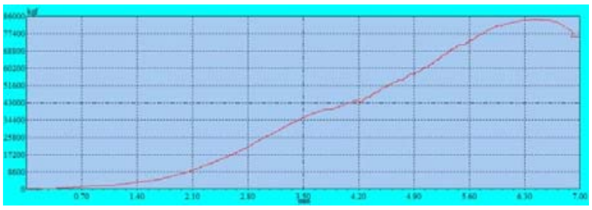


**Figure 8.** The Graph of The Relationship Between Loading and Vertical Deformation forConcrete with *GFRP*

## 5. Discussion & Analysis

From the results of the compressive strength testing of all three types of specimenn, it can be concluded that the concrete with CFRP has a higher compressive strength in comparison with the compressive strength of concrete with GFRP and conventional one. A compressive strength of concrete with CFRP at 28 days old was 44.257 MPa, compressive strength of concrete with GFRP was 38.016 MPa, and conventional concrete compressive strength was 38.98 MPa. The increasing of compressive strength of concrete with CFRP and concrete compressive strength with GFRP was between 26.89%, 14.89% of conventional concrete. CFRP has a high compressive strength than GFRP because CFRP has a high elasticity than GFRP. CFRP has 210 GPa modulus of elasticity, and GFRP has 72 GPa modulus of elasticity.

## 6. Conclusions

The compressive strength of concrete with CFRP theoretically was 54.15 MPa. The compressive strength of concrete with GFRP theoretically was 35.04 MPa. While the normal concrete compressive strength theoretically was 30 MPa. So it can be concluded that the concrete in the presence of CFRP and GFRP theoretically can increase the compressive strength of 44.6%, 14.384% of conventional concrete

The average concrete compressive strength of concrete with CFRP experimentally at 28 days was 44.257 MPa. The average compressive strength of concrete with GFRP at 28 days was 38.016 MPa. While the compressive strength of conventional concrete on average at 28 days old was 32.356 MPa. So it can be concluded that the concrete that contain CFRP or GFRP can increase the compressive strength experimentally of 26.89%, 14.89% of conventional concrete

Therefore, the comparison of my research with other researchers has only differed slightly. As with the research of Remi Eid and Patrick Paultre, the enhancement of compressive strength was 25% for CFRP, and the Research conducted by I Ketut Sudarsana and A.A Gede Sutapa, the enhancement of compressive strength was 11.86% - 15.25% for GFRP.

## References

[1] ACI Committee 440-2R 2008 *Guide of for the Design and Construction of Externally Bonded FRP Systems for Strengthening ConcreteStructures* (America: American Concrete Institute)

[2] Alami Fikri and Ratna Widyawati 2010 Studi Eksperimental Perkuatan Geser Balok Beton Bertulang Dengan Gfrp (Glass Fiber Reinforced Polymer) *Jurnal Rekayasa* **14** (2)
[3] ASCE *Design of Fiberglass-Reinforced Plastic (FRP) Stacks* 2010 (USA: American Society of Civil Engineering)
[4] Basuki Ariyadi 2005 *Sistem Penguatan Struktur Beton Menggunakan Serat Polimer (Fiber Reinforced Polimer)* (Bandung: Berita Teknologi Bahan dan Barang Teknik)
[5] C E Bakis *et al* 2002 Fiber-Reinforced Polymer Composites for Construction-State-of-the-Art Review *Journal Of Composites For Construction 10*.1061/(ASCE)1090-0268(2002)6: **2** (73)
[6] Gangarao Hota V S and Narendra Taly P. V. Vijay 2006 *Reinforced Concrete Design With FRP Composites* (London : CRC Press)
[7] Gere James M and Stephen P Timoshenko 1972 *Mekanika Bahan Jilid 1* (California: Department of Civil Engineering Stanford University)
[8] Gevin McDaniel P E 2014 *Fiber Reinforced Polymer (FRP) Composites* (America: American Composites Manufacturers Association)
[9] Kristianto Anang *et al* 2016 *Studi Eksperimental Penggunaan Pen-Binder dan FRP sebagai Perkuatan Tulangan Tidak Standar pada Kolom Lingkaran* (Bandung)
[10] Petrico G Ireneus 2013 *Perbandingan Kekuatan Lentur Balok Beton Bertulang Dengan Menggunakan Perkuatan CFRP Dan GFRP* (Malang)
[11] Remi Eid and Patrick Paultre 2017 Compressive behavior of FRP-confined reinforced concrete columns *Engineering Structures 132* 518-530
[12] Seracino R 2004 *FRP Composites* (London: A.A.Balkema Publisher)
[13] Sudarsana I Ketut and A A Gede Sutapa 2007 *Perkuatan Kolom Bulat Beton Bertulang Dengan Lapis Glass Fiber Reinforced Polymer (GFRP)* (Denpasar)
[14] Taufikurrahman Parmo 2013 Perbaikan Kekuatan Dan Daktilitas Balok Beton Bertulang Menggunakan Glass Fiber Reinforced Polymer (GFRP) Strips. *Jurnal Ilmu-Ilmu Teknik-Sistem* **10** (3)
[15] US Army Research Laboratory 2002 *Composite Materials Handbook Volume 3. Polymer Matrix Composites Materials Usage, Design, And Analysis* (USA : Department of Defense Handbook MIL-HDBK-17-3F)
[16] SNI 1972 : 2008 Cara Uji Slump Beton (Jakarta : Standar Nasional Indonesia)
[17] SNI 1974 : 2011 Cara Uji Kuat Tekan Beton dengan Benda Uji Silinder (Jakarta : Standar Nasional Indonesia)
[18] SNI 2847 : 2002 Tata Cara Perhitungan Struktur Beton untuk Bangunan Gedung (Bandung : Standar Nasional Indonesia)