A Review of Various Methods for Strengthening RC Beams Subjected to Bending Using FRP Sheets, NSM Plates, and Bar

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Abstract: Recently, reinforced concrete (RC) structures have been strengthened and rehabilitation flexural using different fiber-reinforced polymer materials in more than technique the primary strengthening methods that researchers have studied, both theoretically and empirically. the first technique is a near-surface mounted (NSM) bar, the subsequent method is using a near-surface mounted (NSM) plate, and the third technique is Externally bonded (EB) sheets using one of the four types of FRP or a combination of them. carbon fiber reinforced polymer (CFRP) in the first, the second using armed fiber reinforced polymer (AFRP), the third using glass fiber reinforced polymer (GFRP), and the last one using basalt fiber reinforced polymer (BFRP) due to that Older buildings need to be maintained and repaired because of their exposure to severe environments, increased applied loads, deterioration of reinforcement from corrosion, damage from design or construction mistakes, and inadequate maintenance. This research intends to give an overview of the literature on the Bending behavior of fiber-reinforced polymer (FRP)enhanced (RC beams) under a variety of approaches; Additionally, Attention was also given to the method of manufacturing, the different types and components of fiber, the mechanical properties, and a comparison of the cost of different strengthening techniques. It sheds light on the methods of retrofitting and its various applications.

Keywords:
Flexural; Strengthening; Retrofitted; RC Beams; FRP; CFRP; BFRP; GFRP; AFRP.

1. Introduction

In recent years, studies conducted by researchers into the effective substitution of conventional material of structural members by FRP products are extensively used in a variety of engineering applications dispersed because they are Less expensive than traditional materials, have high strength, good rigidity, lower density, resistance to corrosion, vibration, superior ultimate strain, high durability against fatigue, and low heat conductivity, Lightweight, increase construction speed, helps in cutting expenses on labor and installation[1, 2]. So far, there are numerous published researches on concrete elements reinforced with FRP bars[1, 3]. The reinforcing ratio and the concrete's compressive strength were the two primary factors that were examined. Also, some researchers proposed hybrid systems that combine steel and FRP bars In RC constructions[1]. The significant ductility margin was provided by the partial usage of steel bars. However, in contrast, hybrid-RC has superior strength and resistance to corrosion compared to beams strengthened with steel. [1, 3]. In terms of hybrid FRP reinforcement is a kind of composite that can be situated near the concrete cover's corner to stop the structure from corroding further [4, 5]. However, strengthening is typically a more cost- and environmentally-effective option when repairing and replacing damaged structural elements. compared with demolishing and rebuilding. These kinds of constructions require strengthening with the right materials. RC constructions were strengthened using several methods, including strengthening of FRP sheet [6], laminate [7], and bars [8]. They were used as a substitute retrofit of steel. These days, FRP is often used to refer to reinforcements that are incorporated in an epoxy matrix. These materials are processed from carbon, glass, basalt, or aramid fiber to produce CFRP, GFRP, BFRP, and AFRP, in that order. They are available as bars, strips, or sheets. Instead of using steel plates to strengthen RC structures, FRP is now the most effective material in the world. These systems may be quickly bonded, making them a practical and simple way to replace outdated buildings. This study provides an overview of (FRP) materials. It examines the use of various FRP materials for bending moment strengthening in (RC) beam systems.

2. Manufacturing and Types of fiber Reinforced Polymer Bar and Sheet

2.1. Manufacturing FRP

is a Composite resulting from fibers + polymer matrix Pultrusion manufacturing process: Most common type for FRP bars, structural sections, plates 1- Fiber strand pulled from creels, 2- saturated in polymer resin, 3- shaped in a heated die, 4- the finished product is pulled through as shown in **Figure 1**. Fibers Made of carbon, glass, basalt, or aramid Provide strength and stiffens. Matrix (resin) The matrix or epoxy resin functions as an interface agent in FRP composites composed of epoxy, and vinyl ester, it Protects and transfers load between fibers and binds the fibers together Resins that are most commonly used include thermosetting and thermoplastic polymers. Because it influences the mechanical properties of composites, the selection of resin types during the production process is crucial. Because thermoplastic has less creep and temperature resistance than thermosetting, thermosetting is recommended in the civil engineering field as shown in **Table 1**. The primary forms of FRP are (EB) sheets. [9] or NSM rebar, for example [8], or laminate [10]. FRP was regarded as a structural support material in 1990.

Table 1. The FRP Resin thermosetting matrix characteristics [11].

Resin	Specific gravity	Tensile strength MPa	Tensile Modulus GPa	elongation %
Epoxy	1.22–1.33	60–125	2–4	2–6
Ester vinyl	75–82	1.22–1.33	3–4	6–10.5
Polyester	1–1.5	35-105	2–3.5	6–12

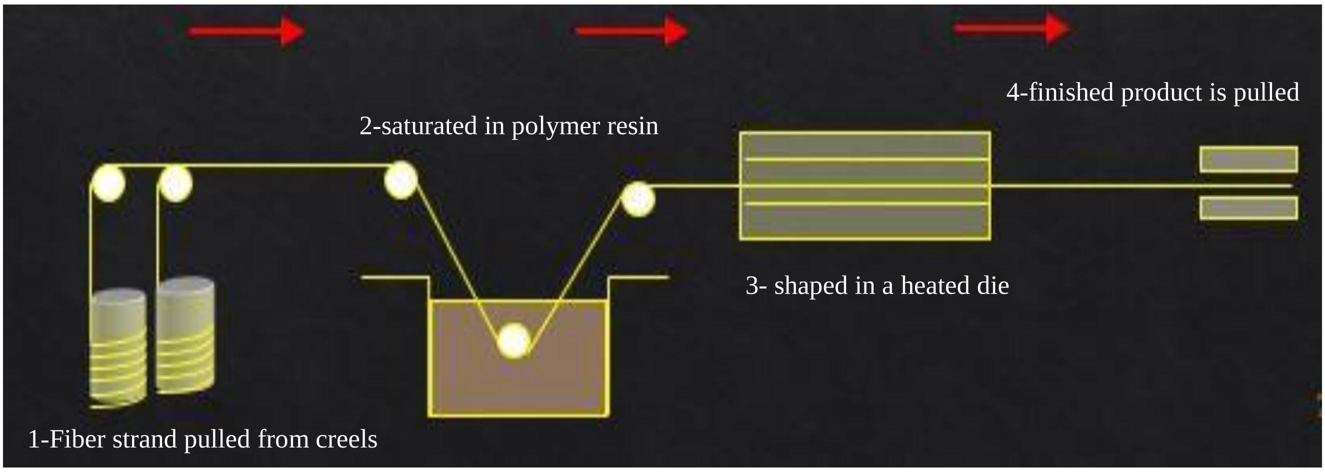

Figure 1. Pultrusion manufacturing process.

2.2. Types of Fiber-Reinforced Polymer Bar and Sheet

Many types of fiber have been tested and used in many facilities, including CFRP, GFRP, BFRP, and ARP. It is the less common type of FRP, including bars and sheets, as shown in. **Figure 2**. Impregnated resins, epoxy, polyester, or vinyl ester are the most commonly used polymers, while Typically carbon, glass, basalt, or aramid fiber strengthen the matrix. The American code[12] talks about three types: CFRP, GFRP, and ARP, and the last type are BFRP. Much research has been conducted on it, but so far it has not been included in the ACI code[12].

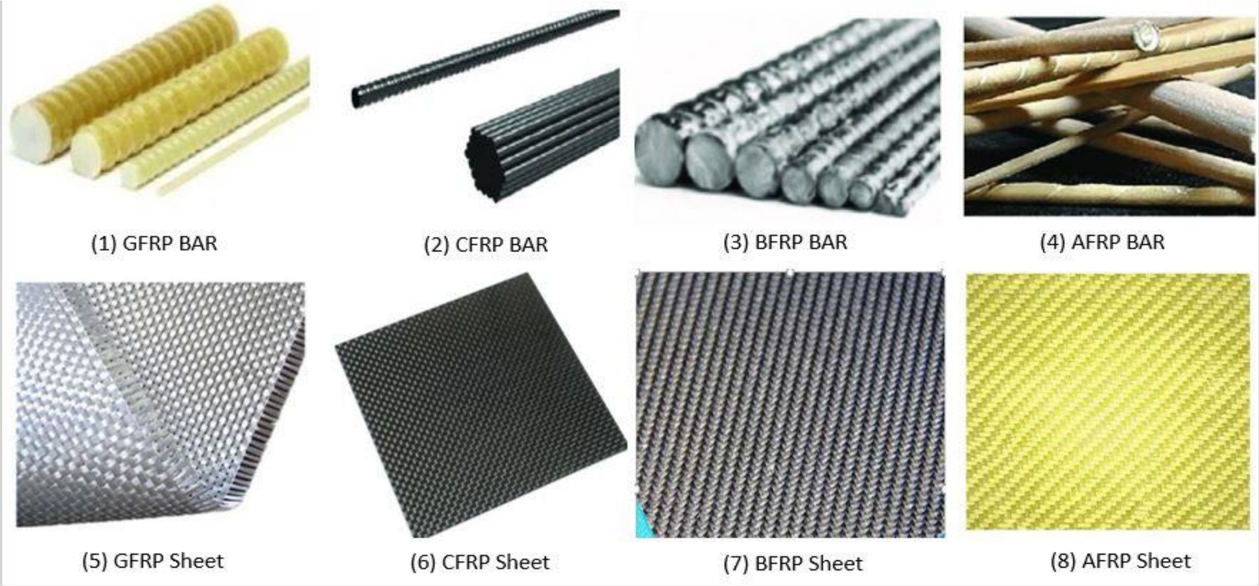

Figure 2. FRP composites:(1) GFRP rebars, (2) CFRP rebars, (3) BFRP rebars, (4) AFRP rebars, (5) GFRP sheets, (6) CFRP sheets (7) BFRP sheets, (8) AFRP sheets[11].

2.2.1. CFRP

CFRP It is one of the most common types because it has special characteristics CFRP is incredibly light and strong with a high tensile strength and strength-to-weight ratio. CFRP possesses an ultra-elastic modulus akin to that of steel the diameter of carbon fiber ranges from 4 to 12 µm. Most carbon atoms in the fibers form crystals that are partially or completely linked along the fiber's long axis. As seen in **Table 2**. In CFRP compounds, the carbon fiber gives strength, and the matrix typically a polymer resin like epoxy keeps the bars together. Despite CFRP's higher cost than steel, when a reduction factor of roughly 55–65% is taken into consideration, the overall cost is lower because CFRP strengthens structural parts exposed to loading, increasing the maximum load [13].

2.2.2. BFRP

Materials with fine fibers with a diameter of approximately 8–18 µm are known as basalt fibers. Resources from the earth such as olivine, pyroxene, and plagioclase are used to make these minerals. [14].BFRP is less expensive than CFRP. Because of its polymeric matrix, BFRP has good strength, fracture elongation, heat resistance, and erosion resistance as well as enhanced stiffness and matrix interference. As shown in Table 2. Many tests and research have been conducted on basalt fiber, but until now it has not been implemented in the ACI code [12]. Estimates of the bars' strength-preservation range from 70% to 90%. Members that are subjected to cyclic stress can be strengthened with the usage of BFRP. One of the main benefits of BFRP over CFRP is its great strength at comparatively low cost. One of the major drawbacks of FRP, except CFRP, is the fact that BFRP has an extremely low tensile modulus, making the structural component non-ductile [13].

2.2.3. GFRP

GFRP is one of the most widely used and widespread types because it is less expensive than traditional material and because it is compatible with the stresses of reinforced concrete because its rupture stress is lower than carbon fiber. Moreover, GFRP referred to as fiberglass, is what makes up glass fiber-reinforced plastic and is typically joined to the mixture at 0.4–2.4% via weight. As seen in **Table 2** GFRP is a type of plastic composite that primarily uses glass fiber to increase its strength and stiffness. Fibers are well protected by the interaction of several substances. Owing to GFRP's affordability and accessibility. GFRP is resistant to heat, salt, chemicals, and the environment. Its strength-to-weight ratio is strong, with values ranging from 8 kg/m2 to 20 kg/m2. Moreover, GFRP is regarded as an excellent insulator and inexpensive reinforcing material. The main benefit of GFRP over other FRP varieties is its low cost. However, its very low tensile strength is its biggest drawback[13].

2.2.4. AFR

Aramid fiber is the less common and widely used type, but it is a strong, heat-resistant synthetic fiber. High-performance fiber made from AFRP. Among the most beneficial composites reinforced with fibers for textiles is AFRP. Because of its robust synthetic fiber composition, it has a 39% lower density than GFRP in **Table 2** and excellent strength, elastic modulus, and heat resistance. In terms of alkaline resistance, AFRP bars outperform CFRP bars in terms of cost. asserts that AFRP performs better under cyclic load conditions, reducing strength by only 13%, or roughly 40% less than conventional FRPs. The main advantages of AFRP are its excellent chemical resistance, good chemical resistance, minimal breakage elongation, and high tensile modulus. However, the primary drawback of AFRP is that it can corrode and degrade when exposed to UV light, necessitating the use of an appropriate covering process[13].

3. Mechanical properties

FRP composites have wide-ranging uses. Their mechanical characteristics give the product they are fashioned into clear advantages. Outstanding mechanical qualities of these materials include their resistance to impact, strength, rigidity, suppleness, and ability to support weights. This gives the composite product superior mechanical characteristics such as robust impact resistance, high fatigue resistance, flexible modulus, shear stiffness, and tensile strength [23] as shown in. **Figure 2**. Table 2 provides a list of FRP qualities for the most popular varieties.

Table 2. Mechanical properties of FRP [15]

Classes	Yield strength (MPa)	Density (g/cm3)	Ult Tensile strength (MPa)	Specific gravity	Elastic modulus (GPa)	Rupture strain (%)
Steel	276-414	6.9–7.9	483-690	7.8	200	>10%
AFRP	N/A	1.29–2.61	1000-2000	1.38–1.39	50-120	2-2.6%
GFRP	N/A	2.11–2.71	483-1500	1.5–2.5	30-55	2-4.5%
BFRP	N/A	2.15–2.71	1035–2150	2.7–2.89	45–59	1.6–3%
CFRP	N/A	1.56–1.77	600-3300	1–1.1	100-1000	0.5-1.7%

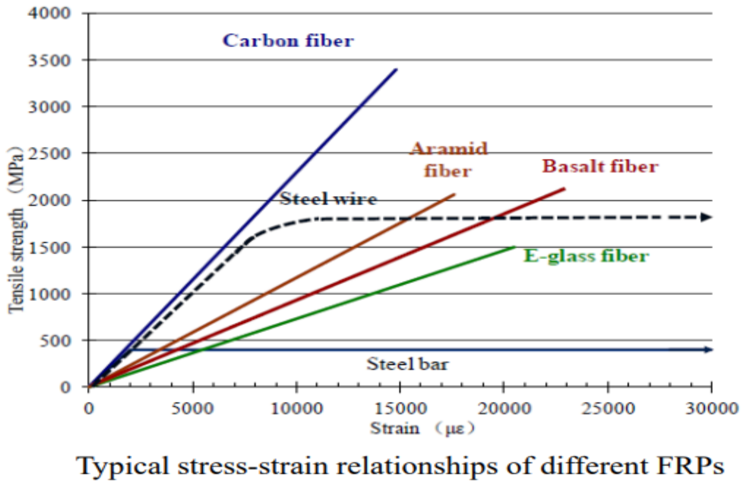

Figure 3. Comparison of steel, wire, and types of FRP [15].

4. Applications of FRP

FRP is mostly utilized in construction applications. including the production of airplanes and cars, reinforcement of concrete structures, and strengthening or rehabilitating deficient structures can be used to strengthen bending moment, sheer[16], and torsion. In more than Tanique it strengthens columns [17], slabs, beams, and walls. It has increased by 50% in the aviation industry, which is a higher percentage than steel, aluminum, titanium, and other metals. FRP was first used in structural buildings in the 1960s. However, it was not until the 1990s that Using the advent of the retrofitted FRP technology for RC structures, the engineering community gradually recognized this new type of material and expanded into the strengthening of steel, wood, and masonry structures.

5. Flexural strengthening of RC beams

RC beams are strengthened as well as rehabilitated with FRP in various ways due to rusting of steel reinforcing bars, damage resulting from design or construction defects, or lack of flexure due to increased applied loads. The flexural strength of the part is determined by the controlled failure mode as shown in. **Figure 2**. EB FRPs are used in various forms, including fully Wrapped and full cross cover for the full length according to the design code specifications whether the FRP should be spaced a certain distance apart, wrapped diagonally, wrapped at the corner, or wrapped vertically along the length Completely. FRP is incorporated into RC concrete using the NSM approach, with strips or bars after construction [15]. To mitigate the lack of ductility in the failure mechanism of FRP, and given that fibers experience brittle and sudden failure, a flexural reduction factor ranging from 0.5 to 0.7 was used when the FRP ratio was less than the equilibrium ratio. Concrete failure has a reduction ratio of 0.65, while FRP fractures have a reduction value of 0.55. The recommended conventional reinforcement percentage is no more than 1.4 times the neutral FRP ratio in both scenarios.

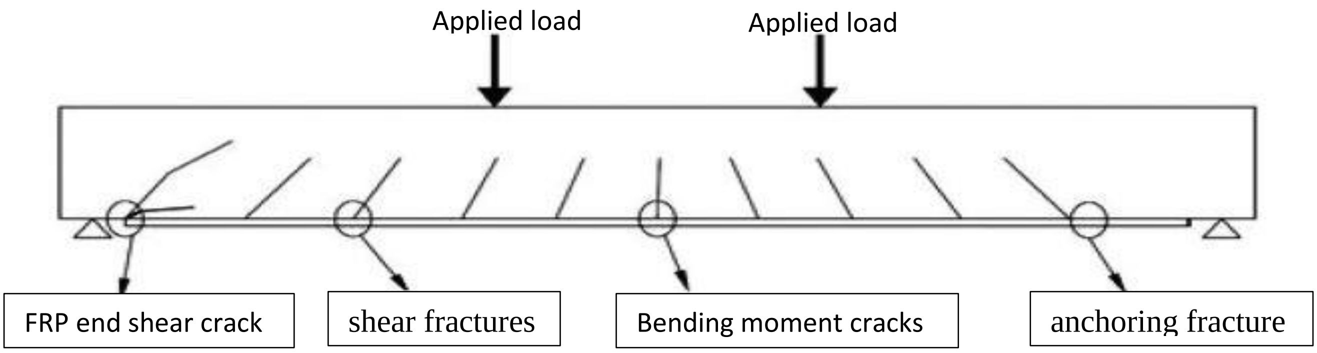

Figure 4. Potential mechanisms of debonding failure in Bending moment[15].

6. Methods of strengthening

Many researchers have used different methods of strengthening concrete structures, especially RC beams, to strengthen RC beams and improve their flexural capacity using three main methods that the ACI code discussed. The first is to use FRP sheets to strengthen the structure by adding a laminated layer at the top or bottom. Based on the inappropriate space, the second is by using an FRP strip retrofitted using the NSM system instead of traditional steel reinforcement, and the third using an FRB bar with the NSM system, which is adding FRP inside the strip by making a trench along the span, cleaning it, then applying epoxy before using it. Concrete surface preparation, such as waterjet and sandblasting, is necessary for EB and NSM FRP. After that, use one of the previous methods, and apply primer and epoxy. Depending on the type of system used, complete processing takes approximately seven days [15-17]. as shown in **Figure 5**.

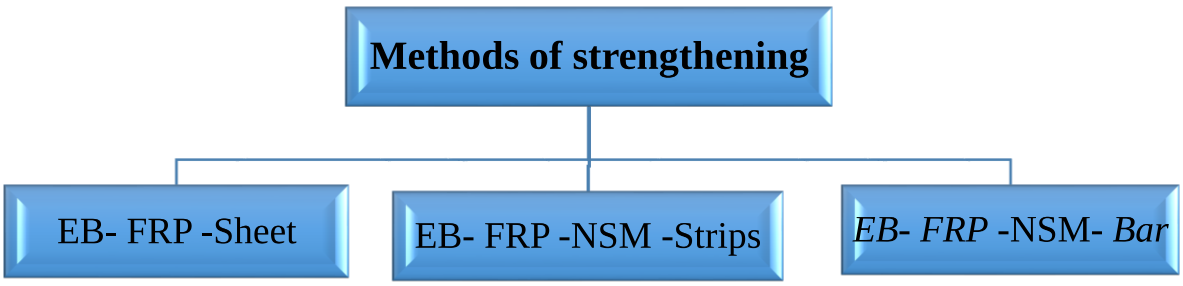

Figure 5. shows different methods for retrofitting of RC structure

6.1. EB FRP sheets

Many researches have been used on the use of EB FRP sheets to retrofit concrete structures, especially reinforced concrete beams under the influence of applied loads, instead of iron because it has high strength compared to Traditional materials is light in weight, and helps workers cut It reduces labor and installation expenses as illustrated in **Figure 6**. and it was discovered that when the number of thickness FRP sheets and Area of the section increased, the flexural capacity greatly increased. EB sheets made of CFRP, BFRP, GFRP, and AFRPS are available Between 65 and 75 percent was the variety of growth in the strengthened beams' Maximum capacity over the control beam specimen. J. Dinesh Kumar et al [18] investigated and found that The retrofitted of reinforced concrete beams was studied Using externally bonded GFRP sheets, it is noted that the externally bonded GFRP used to increase the bending strength of RC beams also resulted in increased crushing load, reduced ductility, and increased ultimate load-carrying capacity. S. Marium Varghese et al [19] CFRP sheets were used for strengthening and changing the compressive strength of concrete. It showed that RC beams retrofitted with CFRP sheets in bending led to an increase in bending moment when the compressive strength of concrete was increased. M. Sai Krishna et al [20] A new idea was used for external retrofitted, which is to support the beam from the sides, and the critical variables that affect the lateral EB-FRP systems were examined For lateral specimens using FRP sheets, there was an improvement in stiffness and load capacity. Kalyani et al [9] The use of a mixture of fiber (HFRP) was studied and it was noted that the HFRP mixture is better than using a single type, which led to an increase in the applied loads, which greatly increases the flexural strength of the RC beams. The ultimate load reached an average of 200% above the guide beam.

Figure 6. EB FRP sheet[20].

6.2. EB FRP strips

NSM strips are comparable to the method of reinforcing bars, with the exception that NSM is added following casting as shown in **Figure 7**. The NSM technology was created in response to the significant EB FRP sheet debonding problem. Compared to the EB FRP sheet, the NSM strengthening exhibits better debonding performance. This process calls for strengthening RC beams with FRP strips. They are cleaned, cement-based adhesives such as epoxy are applied, and they are then placed longitudinally into concrete grooves made by a cutting machine in preparation for installation. based on the ACI code [12]. Additionally, this method behaves better when there is fire. When using the NSM strip, a significant increase in bending strength was obtained in several investigations that studied how RC beams behave with bending but when implementing the EB NSM FRP method, the process of cutting the grooves takes longer and requires more manpower. But to give a very satisfactory result to the reinforcement, grooves with a cross-sectional area proportional to the strip are drilled due to the uneven adhesive surrounding the FRP strip so that they exhibit superior bonding behavior, thus enhancing the strength capacity. [10].

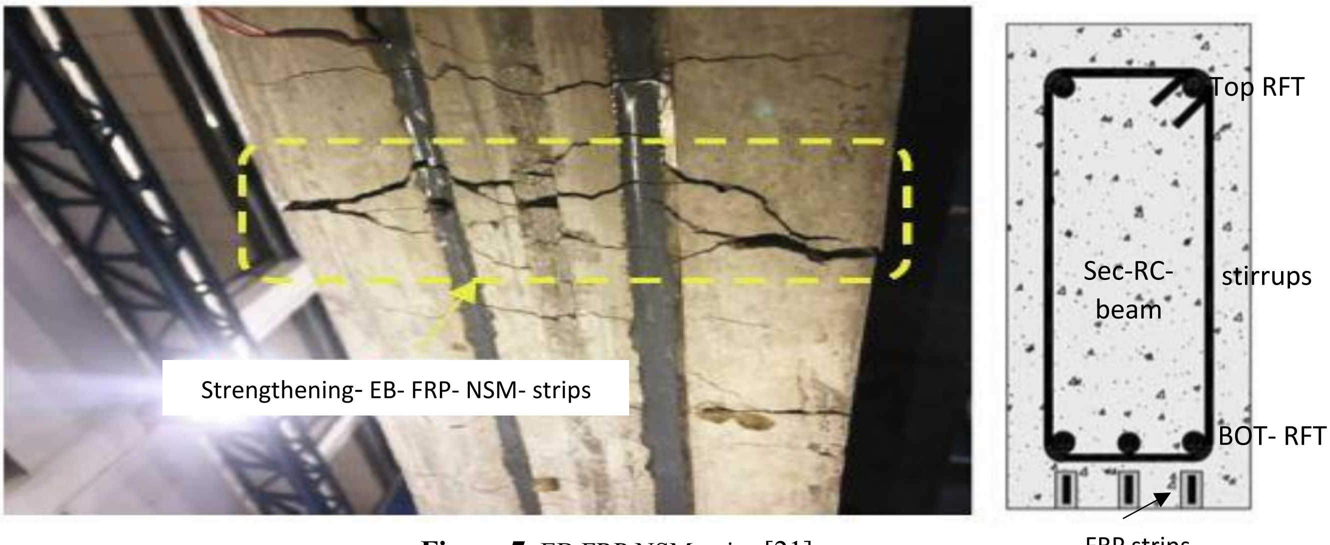

Figure 7. EB FRP NSM strips [21].

6.3. EB FRP bar

FRP that was previously cast as conventional reinforcing is added to reinforce FRP bars in place of steel. Or, as **Figure 8** illustrates, an NSM bar is added after pouring. As per the previously provided description, this technology reinforces RC beams by introducing longitudinally positioned FRP bars into concrete grooves. Numerous studies that used NSM bar strengthening techniques to study the bending behavior of RC beams. I.A. Sharaky et al [22] It was discovered that the Reinforcing steel was used as the main reinforcement at the moment zone and the beam was strengthened with GFRP bars Using GFRP bars as the main reinforcement instead of reinforcement, and strengthening the beam GFRP bars, it was discovered that the GFRP bars that were used enhanced the beam capacity by 61.5% and 59.7%. A.J. Dhaliwal, M. Al-Zu'bi, et al studied the NSM reinforcements were either positioned in the bending moment zone or along the beam. There was a 28% increase in the bending capacity of the strengthened GFRP beams and an 8% enhancement in the bending abilities of the RC beams that were strengthened with NSM bars along their entire span. I. A. Sharaky et al showed improvements in the yielding loads of 155.8% and 129.8%, respectively, while the ultimate loads increased by 165% and 160% for RC beams retrofitted with (GFRP) and (CFRP), correspondingly[8].

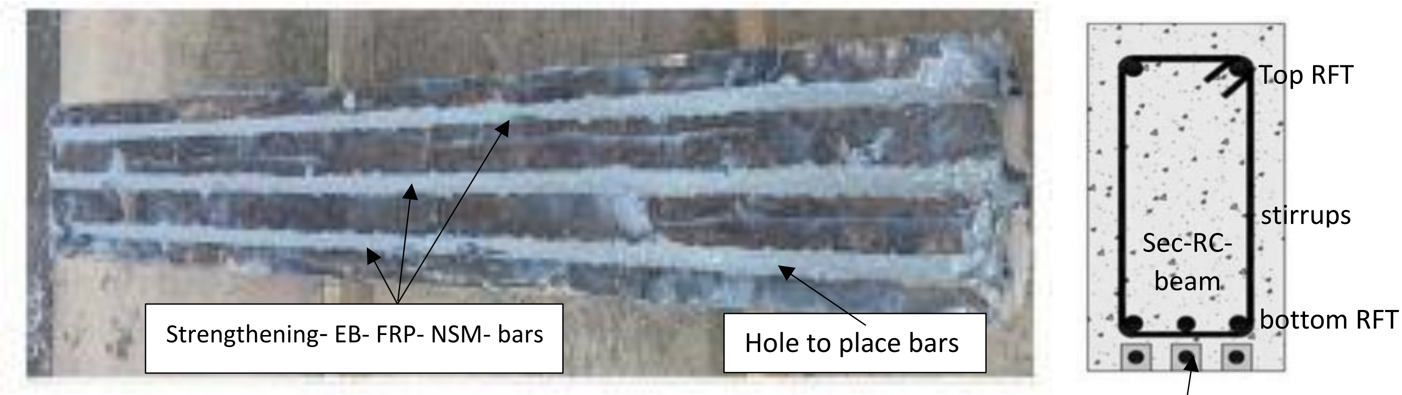

Figure 8. EB FRP NSM bar [22].

7. Conclusions

The above literature reviews lead to the conclusion that (FRP) is a Combination system composed of a polymer resin. For structural member strengthening and restoration, FRP is utilized. Several fiber kinds, including aramid, glass, carbon, and basalt, are employed. Resin, sheet, and laminate are some of the various forms that FRP can take. Both standard reinforcement and NSM strengthening techniques use rebars for reinforcement. Moreover, for flexural strengthening, sheet and laminate are utilized. After reviewing FRP applications for flexural, the following conclusion may be made:

- Increase the service life of structures that have been strengthened using FRP sheets or bars.
- FRP bars offer the best value due to their ability to strengthen construction.
- A variety of buildings Strengthened with FRP bars and FRP sheets work efficiently.
- increasing resistance and ductility, utilizing FRP sheets at the bottom of the RC beam for Bending strengthening is the most effective method compared to jacketing with an FRP sheet.
- The cross-sectional area of FRP sheets greatly influences the bending strength.
- There was an improvement in both the bending stiffness and maximum loads within FRP bars utilized instead of internal reinforcement and the FRP NSM strengthening.
- When using hybrid fiber strips, this led to improved strength and ductility in the RC beam.
- When the width and thickness of the FRP strips, and sheets are increased, this directly increases the beam’s load capacity.
- RC beams that have been side-bonded with FRP sheets had greater stiffness and load-carrying capacity.
- RC beam internally with steel reinforcement and compressive strength equal or higher (fc >50 MPa) and externally retrofitted with NSM CFRP, collapse is a cut in the CFRP Instead of crushing concrete.
- When using strengthening with plates or sheets on all beams, or on the sides, vertical, or inclined at an angle of 45 degrees from the axis, it turns out that inclined sheets at an angle of 45 degrees are more effective than other types.

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