NanoNEXT

Review Article

DOI: 10.54392/nnxt2411

Advancing Concrete Durability: A Comprehensive Review of Wrapping Techniques on Nano Cracks of Structural Members

M. Rushikesh [a], B. Narendra Kumar [a, *]

[a] Department of Civil Engineering, VNR Vignana Jyothi Institute of Engineering & Technology, Hyderabad, Telangana-500090, India

* Corresponding author Email: narendrakumar_b@vnrvjiet.in

DOI: https://doi.org/10.54392/nnxt2411

Received: 31-10-2023; Revised: 09-02-2024; Accepted: 17-02-2024; Published: 21-02-2024

Abstract: The RC structural elements are of the utmost significance in any structure to bear the loads and transfer, while concrete is a brittle material that can bear deformations to some extent. In order to withstand large deformations, various types of wrapping techniques have been introduced, and because of their high load bearing capacity, they have been widely used in RC structures. This review study focuses on the wrapping strategies that are appropriate for RC beam elements, as well as the nature of nano failure cracks. The construction can be earthquake resistant by adopting various wrapping techniques such as BFRP, CFRP, GFRP, AFRP, and so on. The RC beam subjected to various loads such as blast loads, dynamic loads are discussed in this paper. Wrapping approaches have developed as a viable solution for managing restrictions without requiring significant changes to the structural elements. Wrapping approaches are mostly focused on RC beam elements, and numerous methodologies are explored.

Keywords: Fiber-Reinforced Polymers (FRP), Externally Bonded Reinforcement, Bond Behavior, Debonding

1. Introduction

Modern construction still relies heavily on the inherent strength and durability of concrete as a building material. The structural integrity of concrete elements may be affected over time due to the inherent porosity and susceptibility to environmental influences. Innovative wrapping methods have been developed in response to this problem to improve concrete's durability, resist off different types of deterioration, and prolong the lifespan of structures. We look at some of the most popular wrapping methods utilized in concrete structural elements. The usage of FRP materials to augment and improve the flexural capacity of reinforced concrete components has grown significantly during the last few decades. Using the EBR technology, FRP sheets and laminates are put to the surfaces of the members that need to be strengthened. However, many studies on RC flexural members reinforced with EBR have revealed a low efficiency of this approach due to premature FRP debonding failure [1].

Carbon Fiber Reinforced Polymer (CFRP) sheets are a new approach of rehabilitation. As a shear and flexural reinforcement and confinement option for strengthening and repairing concrete structures and infrastructures, EB-CFRP technology has improved significantly [2]. Non-corrosiveness, high transverse tensile strength, stiffness, strength-to-weight ratio, resistance to insect, fungal, and chemical attack, low thermal transmissibility, and ease of installation are all features of CFRP. Because of these unique qualities, CFRP outperforms other typical reinforcing materials such as wire mesh, and textiles [3-5]. Furthermore, CFRP has a unit weight of 1.5-1.6 g/cm3, which is four times lighter than conventional steel; its tensile strength is eight to ten times greater than that of traditional steel reinforcements [6-7].

Soleimani and Banthia (2011) improved impact shear resistance by spraying glass fiber-reinforced polymer (GFRP) on the sidewalls of RC beams. The results of the drop-weight impact tests demonstrated that the specimens with sprayed GFRP layer were exceptionally impact resistant [8]. Beam-column joints are primarily intended for maximum load carrying capability and resistance to horizontal and vertical forces [9]. The majority of study has been done for forces coming from seismic excitation in beam column joints, but relatively little research has been done on the fire performance of RC beam column joints. Several fires broke out in various parts of India this year. When a fire occurs in a building, the strength of the columns and beams deteriorates and nano cracks form. As destruction and replacement of the structure will be costly, upgrading the structure will be less expensive and time consuming [10]. FRP is made up of polymer resin that acts as a matrix or binder with strong fibers.

FRP is made up of polymer resin that acts as a matrix or binder with strong fibers. FRP composites behave differently than conventional construction materials such as reinforcing steel, aluminum, and others (For instance, steel or aluminum are isotropic materials, whereas FRP is anisotropic) [11]. Externally gluing FRP wraps and strips to RC beams with epoxy is a typical strengthening method used to boost the shear capacity of RC beams [12]. The latest developments in composite materials, along with their natural attributes like exceptional tensile strength, effective resistance against fatigue and corrosion, and user-friendly application, position these novel composites as a highly appealing substitute for any other approaches to retrofitting in the realm of concrete repair and reinforcement [13].

2. Wrapping Techniques

Wrapping techniques are used to strengthen beams on the exterior surface of the concrete in order to increase their load carrying capability, flexural strength, and ductility. When beams need to be strengthened owing to deterioration, changes in structural standards, or to meet increasing load demands, these procedures are routinely used. RC beams can be wrapped in a variety of ways, including:

2.1 Wrapping Using Fiber Reinforced Polymer (FRP)

FRP is made up of polymer resin that acts as a matrix or binder with strong fibers. The fibers used to make FRP composites have a high modulus of elasticity, strength, and diameter uniformity. A multitude of factors influence the properties of FRP composites, including type, volume, fiber location, and matrix type. FRP composites have the best mechanical properties in the fiber direction and are very durable and also have a good matrix bond. However, FRP composites have a number of disadvantages, including high initial costs, difficulty bending in the field, insufficient shear strength, low failure strain, and mechanical damage resistance. There are numerous forms of FRP composites, however the following are the most commonly utilized for strengthening and repair.

2.1.1 Carbon Fiber Reinforced Polymer (CFRP)

Carbon Fiber Reinforced Polymer (CFRP) is a high-strength composite material used in engineering applications such as strengthening reinforced concrete (RC) beams. Pultrusion is used to create CRPF strips. The strips are adhered to the surface of the beam using adhesive material and a groove for the glue and strips. Fulling wrapping, u-wrapping, and side wrapping are the three types of CFRP wrapping [14]. CFRP can be utilized as an externally bonded reinforcement or as internal reinforcement in the form of bars or sheets in RC beams. External bonding of CFRP to the surface of RC beams is a popular retrofitting technique used to improve existing structures' load-carrying capacity and flexural performance. Attaching CFRP sheets or strips to the tension face of the beam adds extra tensile strength and confinement. Because GFRP fibers are light in weight, they may be easily attached to the surface of rc components.

2.1.2 Aramid Fiber Reinforced Polymer (AFRP)

Aramid fibers are man-made fibers made from the aromatic polyamide polymer. These fibers have a low density (40% less than GFRP), excellent stiffness and impact resistance, and a strong binding [15]. The composite material aramid-fiber-reinforced polymer (AFRP) is used to strengthen reinforced concrete (RC) beams. AFRP, like CFRP, is constructed of aramid fibers incorporated in a polymer matrix, such as epoxy resin. Aramid fibers, often known as Kevlar in the commercial world, are renowned for their exceptional strength, high modulus, and resilience to impact and fatigue.

2.1.3 Basalt Fiber Reinforced Polymer (BFRP)

Basalt fiber reinforced polymers are made by combining polymer resin and basalt fiber. They are created by melting rocks and extracting thin fibers from the same. The sheets are then constructed to thicknesses ranging from 15 to 25 microns. BFRP rods add ductility to RC beams as well; however, the bond between the concrete and BFRP rods is very good due to their low heat resistance and low cost, which are not commonly used in the field. Such that it can withstand massive deflections. BFRP sheets and rods are used in this review paper to improve the ductility and lifespan of Reinforced Concrete constructions [16].

2.1.4 Glass Fiber Reinforced Polymer (GFRP)

Glass Fiber Reinforced Polymer (GFRP) is a composite material that has gained popularity in the construction industry, especially for reinforcing reinforced concrete (RC) beams. GFRP is composed of a polymer matrix, typically epoxy, reinforced with glass fibers. This combination results in a high-strength, lightweight, and corrosion-resistant material that can be used in place of traditional steel reinforcement in RC beams. At 1,260°C, glass fibers are a heated by using mixture of silica sand, limestone, folic acid, and other components. GFRP has numerous benefits, including high strength, low weight, resistance to high temperatures and heat, great thermal insulation, and a low cost [17].

2.1.5 Ultrahigh Molecular Weight Polyethylene

Ultra-high molecular weight polyethylene is a thermoplastic polymer (UHMWPE) Which is laminated at the soffit of the RC beam to resist the flexural bond and is renowned for its outstanding strength. The epoxy adhesives are used It bonds the protective wrapping material for surfaces that need improved wear resistance. UHMWPE sheets or tapes are applied to surfaces using the wrapping technique to bear more loads and to act the beam as a ductile material.

3. Materials Utilized in Strengthening and Wrapping Techniques

3.1 Ultrahigh Molecular Weight Polyethylene

UHMW polyethylene is a thermoplastic polymer with high strength, hardness, and minimal friction. It possesses excellent wear resistance, impact strength, and self-lubricating qualities due to its high molecular weight. It is a valuable material in a range of engineering applications, including the retrofitting of reinforced concrete (RC) beams, due to its specific properties [18].

Table 1. Properties of UHMW [18].

Description	Ultrahigh molecular weight polyethylene
Thickness in terms of mm	0.5
Young's modulus (GPa)	175
The tensile strength (MPa)	2400
Ultimate strain	0.019
Specific Gravity (g / cm³)	0.935

Figure 1. Aramid Fiber [19].

Table 2. Properties of Aramid fiber [20]

Fiber type	Density (g m^{-2})	Thickness (mm)	Tensile Strength (Mpa)	Tensile Modulus (Gpa)	Elongation (%)
Aramid Fiber	415	0.286	2206	131	2.1

Figure 2. 3-Point loading frame [18].

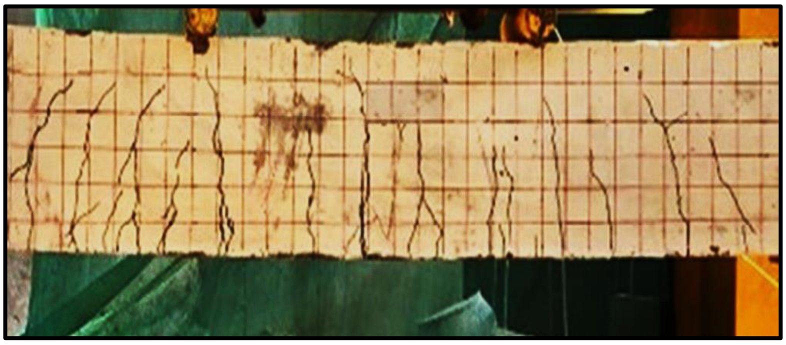

Figure 3. Failure pattern of RC beam Specimen [18].

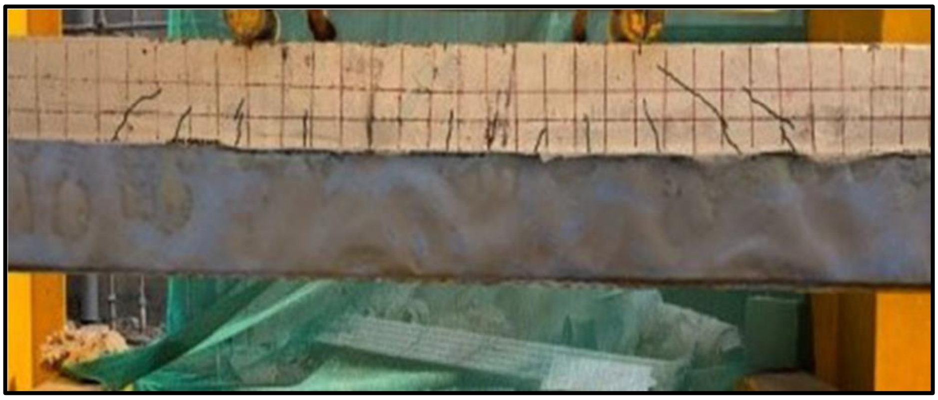

Figure 4. Failure pattern of retroffited RC beam Specimen [18].

3.2 Aramid fiber reinforced polymer

The aramid fiber reinforced polymer (AFRP) is a unidirectional membrane with a thickness of 0.028 cm and a width of 1.25 cm made of Twaron HM 1055 (Eurocarbon, 301 Aramid UD Tape). The fiber has an young's modulus of 105 GPa and a failure elongation of 2.8%. Aramid fiber is simple to recycle and use again in the production of pulp products [19]. AFRP materials have a remarkable elastic modulus and tensile strength. For example, carbon fibers have tensile strengths that are many times greater than those of steel, allowing them to support heavy loads without experiencing significant deformation [20].

3.3 Basalt fiber reinforced polymer

According to the manufacturer, the tensile strength, modulus of elasticity, and ultimate strain of the BFRP bars are 1168 MPa, 48 GPa, and 0.023, respectively [21]. BFRP materials have exceptional tensile strength, which is often in the 800-1200 MPa range. This characteristic guarantees that the reinforcement in a structural component, such as a beam, may effectively sustain tensile loads, preventing cracking and boosting total load-bearing capacity. This material can be used to replace the quantity of steel reinforcement in RC beams and improve the beam's ductility [22]. For BFRP materials, the elastic modulus typically ranges from 50 to 100 GPa. This characteristic denotes the material's stiffness and its capacity to withstand deformation under applied loads, which helps to improve the reinforced structure's overall performance and rigidity [23]. A common range for the flexural strength of BFRP reinforcements is 700–1000 MPa. For structural members like beams to resist bending moments and avoid excessive deflection, this feature is essential [24].

4. Wrapping Techniques Studies-RC Structural members

4.1 Ultrahigh Molecular Weight Polyethylene

All reinforced concrete conventional beams and retrofitting beams laminated with UHMW PE are conceptually and practically studied. The primary tension reinforcement is reduced to achieve flexural deficient beams. Flexural capacity may be increased by using UHMW PE [25]. The load carrying capacity of the RC beam increases as the percentage of steel is varying, the flexural capacity is increasing. When tested under 3-point loading deflection rate was declined at a rate 5% for 30% of steel reinforcement ratio [26].

In the experiments, the explosive was used; It was precisely strung by a rope above the beam midspan and adjusted to the right height for each scenario. A detonator was used to ignite the explosive in the center of the block. The impact due to blast loads are determined using finite element analysis. The RC structural elements can be utilized in military applications since they are blast proof [27].

When UHMWPE fibers are added to beams, the Degree of damage is substantially decreased when compared to equivalent standard RC beams subjected to blast loads; the hazard of injuries and fatalities caused by concrete fragments is also greatly reduced [28]. Fibers have a high resistance to fracture formation and development, which promotes the safety of RC structural elements The length of the crack on the bottom surface begins to shorten in comparison to the length of the fracture on the top surface. The blast resistance differences between the two types of RC beams were examined and assessed, and the UHMWPE fibers' blast-resistance-enhancement mechanism was revealed [29]. For modeling and computations, the finite-element-simulation program LS-DYNA was used, and the variations in damage characteristics with scaled distance were explored based on test results verification [30].

4.2 Fiber Reinforced Polymer

DenepoxTM 40 structural epoxy was used to repair pre-damaged beams. Using a high-pressure pump with a thin nozzle, this epoxy was injected into all visible fissures. DenepoxTM-40 is a two-part epoxy resin with exceptionally low viscosity, designed for structural injection within concrete constructions, offering a tensile strength surpassing 50 MPa [15].

The applied load rose monotonically at a rate of 0.1 cm/s in a quasi-static displacement-control mode. Three Linear Variable Displacement Transducers (LVDTs) are attached to each beam specimen, one at the midspan bottom of the beam and two in the center of the right and left shear spans. Furthermore, five strain gauges were installed to monitor the strain reaction of the stirrups and flexural reinforcement, and four strain gauges were installed to monitor the strain response of the CFRP strips. Nano cracks were regularly checked throughout the test [16].

Typically, a thermosetting resin like epoxy, polyester, or vinyl ester serves as the polymer matrix. The fibers are enclosed and connected by this matrix, which offers stability, weight transfer, and defense against the elements. The strength of the reinforcing fibers has a significant impact on the tensile strength of FRPs. For instance, carbon fibers are suited for applications needing strong load-bearing capacities due to their extraordinarily high tensile strength. FRPs have exceptional corrosion resistance, which is beneficial in harsh settings where conventional materials may eventually disintegrate [19].

4.3 Fiber Reinforced

Beams were cast so they comply with the ACI 440.1R-15 specification in terms of spacing of bars, clear cover between bars and material, and required depth. Furthermore, a/d > 3 span-to-depth was assessed to ensure the specimens' slenderness. The overall cross sectional size is 180 mm x 230 mm. The beams were 2200 mm lengthwise and had an approximate 1900 mm clear span. To prevent shear failure, steel stirrups with a diameter of 10 mm were used at 100 mm distances. [20]. In this work, the four-point loading system was employed to assess the flexural response of all beams. The tests were carried out using an (UTM) Instron universal testing machine having jacks directly attached to a spreader beam at a displacement control mechanism rate of 1 mm a minute [22]. The spreader beam equally distributes the load on two points apart from the specimen's end support, resulting in an evenly distributed (constant) maximum moment region. BFRP has an excellent ratio of strength to weight due to its strong tensile strength and light weight. This characteristic enhances the bearing capacity of RC beams in terms of loading without introducing too much dead load. Due of its substantial tensile strength and small weight, BFRP has a high strength-to-weight ratio [21]. This characteristic enhances the load-bearing capacity of RC beams without introducing too much dead load. In applications where electrical conductivity must be kept to a minimum, such as near power lines or in constructions vulnerable to electromagnetic interference, BFRP's non-conductive nature is useful.

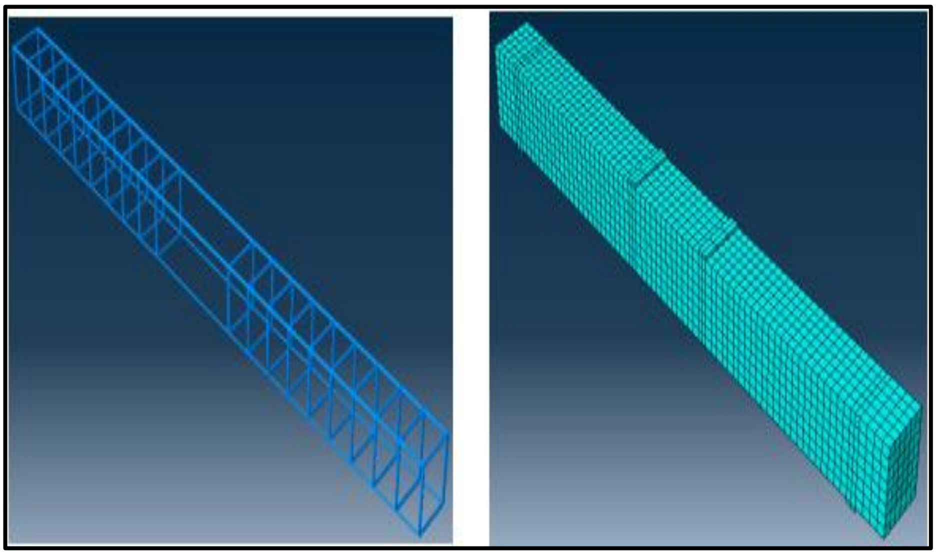

Figure 5. FEM model reinforcement skeleton and mesh modelling of RC beam [21].

Table 3. Tensile strength values of ballast reinforced fiber polymer [21]

Tensile Strength (Mpa)	Reduction	Moment (kN.m)	Deflection Δ (mm)
1200	0%	14.08	42.88
1080	10%	12.98	37.94
960	20%	12.19	34.57
840	30%	10.77	28.70

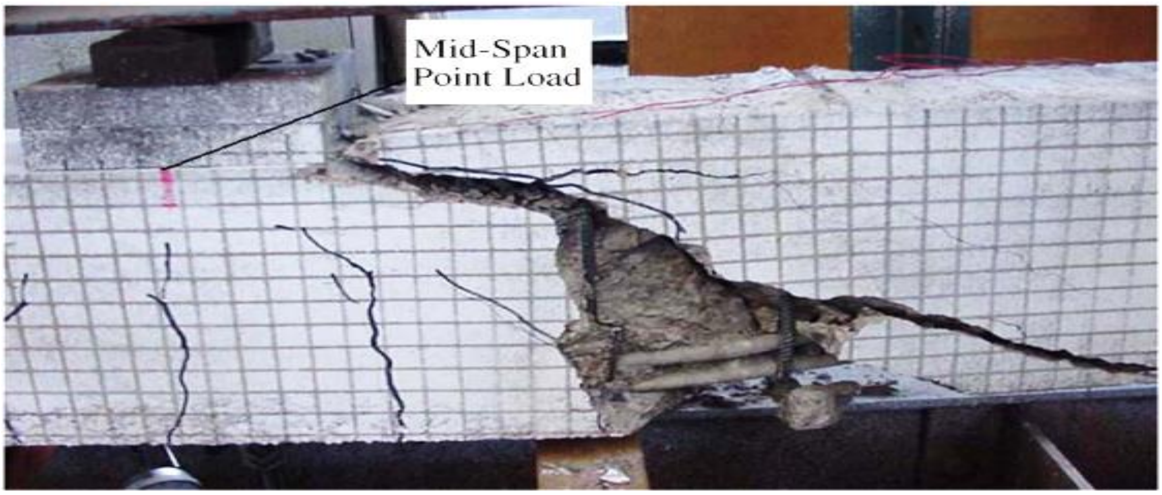

Figure 6. The conventional specimen tested under 3-point loading [15].

Figure 7. The Rupture failure of GFRP specimen [15].

4.4 Glass Fiber Reinforced Polymer (GFRP)

Sprayed Glass Fiber Reinforced Polymer (GFRP) has emerged as a highly efficacious and promising method to enhance the shear capacity of Reinforced Concrete (RC) beams when subjected to the rigorous conditions of impact loading. This new composite material, made up of a painstakingly tailored blend of glass fibers and high-strength polymers, demonstrates a compelling capacity to improve the structural integrity of RC beams, particularly in terms of lateral load resistance [12]. When faced with the tremendous issue of impact loading, traditional RC beams frequently experience limitations in their ability to bear the abrupt and dynamic forces put on them. The development of the Sprayed GFRP technology, on the other hand, has proven to be a game changer, offering a synergistic combination of reinforced concrete and cutting-edge fiber-reinforced polymers [13].

The author's investigations show that connecting GFRP plates to the tension face of reinforced concrete beams can result in a significant increment in flexural strength. In beams with lower steel reinforcing ratios, the increase in ultimate flexural strength was more evident. At all stress levels, plating also reduced fracture size in the beams. This technology's correct implementation necessitates accurate preparation of the concrete surface as well as the selection of a long-lasting epoxy. The GFRP plating lowered the beams' ductility marginally [10].

The maximum load bearing capability of RC beams with GFRP plating is improved by 35% to 40% depending on the outer ply layer. All shear deficient beams disintegrated, according to testing data, due to the creation of a large diagonal fracture of stress running from the supports to the loading point. Failure to succeed as stirrup distance and displacement rose, the stresses of the shear deficient beams dropped, indicating brittle failure [11].

5. Enhanced Flexural Strength of Structural Members After Wrapping Techniques

Utilizing Fiber-Reinforced Polymer (FRP) wrapping methods leads to a substantial improvement in the flexural strength of diverse structural components. These techniques have a significant influence on various aspects of structural performance:

To begin with, they contribute to bolstering and augmenting the load-carrying capacity of essential structural elements like beams, columns, and slabs. By enhancing the capacities for flexure, shear, and axial loads in concrete and masonry elements, these approaches empower existing structures to bear heavier loads and adhere to updated design criteria. Furthermore, the application of wrapping techniques based on FRP materials yields heightened resistance to seismic forces. Structures fortified with FRP materials display improved ductility and superior energy dissipation properties, mitigating the potential for brittle failures during seismic events. Another advantage lies in the sustainability and eco-friendliness of FRP materials. In contrast to traditional materials such as steel, FRP materials exhibit a reduced carbon footprint due to their energy-efficient manufacturing processes. Additionally, their extended lifespan contributes to a reduction in waste generation over time, aligning with environmentally mindful construction practices [23].

The lightweight characteristics and resistance to corrosion of FRP materials, encompassing variations like Glass FRP (GFRP), Aramid FRP (AFRP), and Basalt FRP (BFRP), further enhance their attractiveness. Unlike conventional steel reinforcement, these materials remain unaffected by rust, ensuring prolonged structural soundness and minimizing the need for recurrent upkeep and repairs [24-26]. The ease of application and installation is another advantage of FRP wrapping techniques. The streamlined procedures, coupled with minimal equipment requirements, render these methods more efficient and expedient in comparison to traditional retrofitting approaches. This efficiency translates into potential cost savings and decreased disruptions during construction or retrofitting endeavors. The endurance and longevity of FRP materials in diverse environmental conditions, including moisture, chemicals, and ultraviolet radiation, significantly contribute to the extended operational life of reinforced structures [27-30]. Their resilience when exposed to extreme circumstances further underscores their potential to prolong the lifespan of constructed assets.

The versatility and adaptability of FRP wrapping techniques are noteworthy. These methods can be seamlessly applied to a wide array of structural materials, encompassing concrete, masonry, and wood. This adaptability enables the creation of customized solutions for intricate geometries and irregular configurations, highlighting the inherent flexibility within FRP-based strengthening strategies.

6. Remedial Measures

- **Surface Preparation:** If poor adhesion or bonding resulted from improper surface preparation, repair may entail thorough cleaning, the removal of pollutants, and even roughening the surface to guarantee appropriate adhesion of the wrapping material.
- **Wrinkling:** If the wrapping material buckles or wrinkles, corrective actions could include carefully reapplying the material, smoothing out creases, and making sure that the installation was done with the right tension.
- **Adhesive Failure:** Remedial actions may include carefully removing the damaged area, applying adhesive again, and making sure the right curing conditions are present if the adhesive that was used to connect the wrapping material fails.
- **Inadequate Load-Bearing Capacity:** Remedial steps may be taken if the wrapped structure does not reach the intended load-bearing capacity by increasing the number of wrapping layers, changing the fiber orientation, or revising the design specifications.

7. Limitations

Wrapping techniques applied to Reinforced Concrete (RC) beams offer advantages, but they also come with a range of limitations that warrant careful consideration when used for structural reinforcement. These constraints encompass challenges when dealing with heavily damaged beams, where the effectiveness of wrapping materials might diminish due to compromised concrete surfaces. Complex beam shapes and irregular configurations introduce difficulties in ensuring consistent application of the wrapping material, potentially resulting in uneven distribution of stress. The success of wrapping methods hinges on meticulous surface preparation, as any lingering impurities or inadequate surface roughness can impede the crucial bonding between the wrapping material and the concrete substrate. Furthermore, extreme temperatures and harsh environmental conditions can impact the performance of wrapping materials, hastening the degradation of adhesives and material integrity over time. An essential concern is the possibility of debonding, which can arise from insufficient installation methods or surface preparation, leading to compromised load transfer mechanisms [31-32].

The compatibility of wrapping materials with existing steel reinforcement, coupled with the need for ongoing vigilance and maintenance, further contributes to the intricacies of their application. The uncertainties regarding their long-term efficacy, along with the specialized expertise and associated costs, must be carefully evaluated against the potential benefits. Additionally, it's important to recognize that wrapping techniques may face restrictions outlined in design codes, emphasizing the requirement to assess their appropriateness within the framework of regulatory guidelines and project specifications [33-34]. Wrapping techniques applied to Reinforced Concrete (RC) beams offer advantages, but they also come with a range of limitations that warrant careful consideration when used for structural reinforcement. These constraints encompass challenges when dealing with heavily damaged beams, where the effectiveness of wrapping materials might diminish due to compromised concrete surfaces. Complex beam shapes and irregular configurations introduce difficulties in ensuring consistent application of the wrapping material, potentially resulting in uneven distribution of stress. The success of wrapping methods hinges on meticulous surface preparation, as any lingering impurities or inadequate surface roughness can impede the crucial bonding between the wrapping material and the concrete substrate [35].

Furthermore, extreme temperatures and harsh environmental conditions can impact the performance of wrapping materials, hastening the degradation of adhesives and material integrity over time. An essential concern is the possibility of debonding, which can arise from insufficient installation methods or surface preparation, leading to compromised load transfer mechanisms [36]. The compatibility of wrapping materials with existing steel reinforcement, coupled with the need for ongoing vigilance and maintenance, further contributes to the intricacies of their application. The uncertainties regarding their long-term efficacy, along with the specialized expertise and associated costs, must be carefully evaluated against the potential benefits. Additionally, it's important to recognize that wrapping techniques may face restrictions outlined in design codes, emphasizing the requirement to assess their appropriateness within the framework of regulatory guidelines and project specifications.

8. Conclusions

The use of wrapping techniques has a lot of potential in a variety of fields and applications. The adaptability of wrapping techniques, along with their capacity to increase functional performance, protection, and structural integrity, highlight their significance in contemporary engineering and design. The review has highlighted the wide variety of wrapping materials, strategies, and factors while highlighting their critical function in tackling problems and maximizing solutions. It is clear from a thorough examination of the literature that wrapping techniques provide a flexible way to increase longevity, improve load-bearing capacity, and lower maintenance needs. The effectiveness and creativity shown by wrapping methods are compelling, whether in the context of fiber-reinforced polymers enhancing existing structures, Ultra-High Molecular Weight Polyethylene optimizing wear resistance, or even novel applications like basalt fiber-reinforced polymer in structural reinforcement.

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Acknowledgement

The authors acknowledge that this study is supported by VNRVJIET and authors who are contributed in this area.

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Yes

Conflict of interest

The Authors declares that there is no conflict of interest anywhere.

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