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Review On Experimental Study on Enhancing the Flexural Strength of Pre-Loaded RC Beams Using BFRP And GFRP Bar by NSM Method

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***Abstract*—The deterioration of reinforced concrete (RC) structures due to aging, overloading, and environmental effects has increased the need for effective strengthening and rehabilitation techniques. This study investigates the enhancement of flexural strength of pre-loaded RC beams using Near Surface Mounted (NSM) Basalt Fiber Reinforced Polymer (BFRP) and Glass Fiber Reinforced Polymer (GFRP) bars. The NSM technique is considered an efficient retrofitting method because of its improved bond performance, durability, and ease of application compared to conventional strengthening methods.In this experimental study, RC beam specimens are initially cast and pre-loaded to simulate damaged structural conditions. Grooves are then created in the tension zone of the beams, and BFRP and GFRP bars are inserted using epoxy adhesive. The strengthened beams are tested under two-point loading to evaluate their flexural behavior, load-carrying capacity, deflection, crack pattern, stiffness, and failure modes.The study aims to compare the effectiveness of BFRP and GFRP bars in improving the structural performance of pre-loaded RC beams. The results are expected to show considerable enhancement in flexural strength and stiffness, along with reduced crack propagation. This research highlights the potential of NSM-FRP strengthening as a sustainable and reliable rehabilitation technique for damaged RC structures in modern construction engineering**

***Index Terms*—Reinforced Concrete (RC) Beam, Flexural Strength, Pre-Loaded Beams, Near Surface Mounted (NSM) Method, Basalt Fiber Reinforced Polymer (BFRP), Glass Fiber Reinforced Polymer (GFRP), Structural Strengthening, Retrofitting of Structures, Fiber Reinforced Polymer (FRP), Load Carrying Capacity, Deflection Behaviour, Crack Pattern, Structural Rehabilitation**

I. INTRODUCTION

Reinforced concrete (RC) structures are widely used in modern construction due to their high strength, durability, and versatility. However, many RC structures experience deterioration over time because of factors such as overloading, corrosion of reinforcement, environmental exposure, poor construction practices, and seismic effects. These conditions often lead to cracking, excessive deflection, and reduction in load-carrying capacity, thereby affecting the safety and serviceability of the structure. Strengthening and rehabilitation of damaged RC members have therefore become important aspects of structural engineering.

Among various retrofitting techniques, Fiber Reinforced Polymer (FRP) composites have gained significant attention because of their high strength-to-weight ratio, corrosion resistance, and ease of installation. In recent years, the Near Surface Mounted (NSM) technique has emerged as an effective method for strengthening RC beams. In this method, FRP bars are inserted into grooves made in the concrete cover and bonded using epoxy adhesive, resulting in improved bond performance and better utilization of FRP materials compared to externally bonded reinforcement systems.

Basalt Fiber Reinforced Polymer (BFRP) and Glass Fiber Reinforced Polymer (GFRP) bars are increasingly being used in strengthening applications due to their lightweight nature, non-corrosive properties, and excellent mechanical performance. BFRP bars offer higher durability and thermal resistance, while GFRP bars provide an economical strengthening solution with good tensile strength.

This study focuses on the experimental investigation of enhancing the flexural strength of pre-loaded RC beams using BFRP and GFRP bars through the NSM method. The beams are pre-loaded to simulate damaged structural conditions and then strengthened using FRP bars. The behavior of strengthened beams is evaluated in terms of load-carrying capacity, deflection, crack pattern, stiffness, and failure modes. The study aims to compare the effectiveness of BFRP and GFRP bars in improving the structural performance of damaged RC beams and to assess the suitability of the NSM technique as a reliable rehabilitation method for existing concrete structures.

II. LITERATURE REVIEW

This section reviews previous research on the use of waste glass powder as a partial replacement for fine aggregates in concrete. Various studies conducted by different researchers are briefly discussed, focusing on the effects of glass powder on the mechanical and durability properties of concrete. Special attention is given to parameters such as particle size, replacement percentage, and curing conditions. The influence of glass powder on workability, compressive strength, and microstructural behavior is also highlighted. The collected findings help in identifying key trends, benefits, and limitations, while also indicating areas where further investigation is needed.

De Lorenzis and Teng (2007) [1] This study investigated the effectiveness of the Near Surface Mounted (NSM) technique for strengthening reinforced concrete structures using FRP bars. The authors observed that NSM systems provide better bond behavior and higher load transfer efficiency compared to externally bonded reinforcement methods. Experimental results showed considerable improvement in flexural strength, stiffness, and crack control of RC beams. The study also highlighted that the NSM method reduces premature debonding failures and offers better durability due to the protection provided by the concrete cover around the FRP reinforcement.

Hassan and Rizkalla (2004) [2] The researchers experimentally evaluated RC beams strengthened with NSM GFRP bars under flexural loading conditions. The study showed that the strengthened beams exhibited higher ultimate load-carrying capacity and reduced mid-span deflection compared to control beams. Improved crack distribution and delayed crack propagation were also observed. The authors concluded that NSM GFRP bars effectively enhance the structural performance of damaged RC beams. The research further emphasized that proper epoxy bonding and groove dimensions play an important role in achieving efficient strengthening performance and long-term durability..

Nanni et al. (2001) [3] This paper focused on the behavior of reinforced concrete beams strengthened with FRP reinforcement systems. The experimental investigation demonstrated that FRP strengthening effectively restores the flexural strength of damaged beams and increases stiffness. The study observed improved load-deflection response and reduced crack widths after strengthening. Different failure modes such as FRP debonding and concrete crushing were analyzed. The authors concluded that FRP reinforcement is a reliable retrofitting solution for deteriorated RC structures and can significantly improve the structural safety and service life of existing concrete members.

El-Hacha and Gaafar (2011) [4] The study investigated the flexural performance of RC beams strengthened with NSM FRP bars. Experimental results indicated that the NSM system significantly increases load-carrying capacity, stiffness, and crack resistance. The authors examined the bond interaction between FRP bars, epoxy adhesive, and concrete substrate and found that proper bonding enhances strengthening efficiency. The research highlighted that NSM strengthening provides better anchorage and utilization of FRP materials than externally bonded techniques. The authors recommended NSM FRP systems as an effective and durable solution for structural rehabilitation applications.

Sharaky et al. (2014) [5] This research experimentally evaluated the influence of groove dimensions and adhesive properties on the behavior of NSM FRP strengthened RC beams. The study found that appropriate groove size and proper epoxy application significantly improve bond strength and load transfer efficiency. Strengthened beams showed higher flexural capacity, reduced crack widths, and improved stiffness compared to conventional beams. Different failure modes were also analyzed to understand the performance of the NSM system. The authors concluded that design parameters of the NSM technique greatly affect the overall strengthening effectiveness of RC beams.

Kotynia (2008) [6] The paper investigated the flexural behavior of reinforced concrete beams strengthened with CFRP and GFRP bars using the NSM technique. Experimental results demonstrated significant enhancement in flexural strength and stiffness of the strengthened beams. The study also reported improved ductility and better crack distribution under loading. The failure mechanisms of the beams were analyzed, including FRP rupture and concrete crushing. The author concluded that NSM FRP reinforcement effectively increases the structural capacity of RC beams and provides a reliable strengthening solution for damaged and under-designed structures.

Barros and Fortes (2005) [7] This study examined the application of the Near Surface Mounted (NSM) technique for the rehabilitation of reinforced concrete structures. The authors observed that NSM FRP bars provide excellent bond characteristics and improved structural efficiency compared to externally bonded systems. Experimental results showed significant improvement in flexural strength, stiffness, and crack control. The study also highlighted the advantages of the NSM method, including ease of installation, protection of FRP reinforcement from environmental damage, and better durability. The authors concluded that NSM strengthening is an effective solution for repairing deteriorated RC beams.

Al-Mahmoud et al. (2010) [8] The researchers investigated the flexural performance of RC beams strengthened using GFRP bars. The study showed that GFRP strengthening significantly increased the ultimate load-carrying capacity and reduced crack widths under service loads. Improved stiffness and better deflection behavior were also observed in strengthened beams. The paper emphasized the corrosion resistance and lightweight nature of GFRP bars, making them suitable for rehabilitation works. The authors concluded that GFRP bars provide an economical and durable strengthening solution for reinforced concrete structures exposed to aggressive environmental conditions.

Ceroni (2010) [9] This paper focused on repairing pre-cracked RC beams using FRP strengthening systems. Experimental investigations revealed that FRP-repaired beams regained a significant portion of their original load-carrying capacity and stiffness. The strengthened beams also exhibited reduced crack propagation and improved flexural behavior compared to damaged control beams. Different strengthening configurations and failure modes were studied to evaluate repair effectiveness. The author concluded that FRP systems are highly suitable for restoring damaged RC beams and extending the service life of existing concrete structures subjected to deterioration or overloading.

Seracino et al. (2007) [10] The study investigated the bond behavior of NSM FRP bars embedded in concrete beams using epoxy adhesives. Experimental results showed that bond strength between FRP bars and concrete plays a crucial role in determining strengthening effectiveness. The authors observed that proper groove dimensions and adhesive properties significantly improve load transfer and prevent premature debonding failures. Strengthened beams exhibited enhanced flexural strength and crack resistance. The research concluded that careful design of the bond interface is essential for achieving efficient and durable NSM FRP strengthening performance in reinforced concrete structures.

Aslam et al. (2015) [11] This research evaluated the structural performance of Basalt Fiber Reinforced Polymer (BFRP) bars in reinforced concrete applications. The study reported that BFRP bars possess high tensile strength, corrosion resistance, and lightweight properties, making them suitable for strengthening damaged RC structures. Experimental findings showed improved flexural performance and crack resistance in beams reinforced with BFRP bars. The authors also highlighted the environmental benefits of basalt fibers as a sustainable material. The study concluded that BFRP reinforcement is a promising alternative to conventional steel reinforcement in structural rehabilitation works.

Sim et al. (2005) [12] The authors investigated the durability performance of BFRP bars under different environmental conditions. The study examined the effects of temperature, moisture, and chemical exposure on the mechanical properties of basalt fibers. Results indicated that BFRP bars exhibit good thermal stability, corrosion resistance, and long-term durability compared to conventional reinforcement materials. The research also showed that BFRP bars maintain adequate tensile strength even after environmental exposure. The authors concluded that BFRP reinforcement can effectively enhance the durability and service life of concrete structures in aggressive environments.

Wu et al. (2012) [13] This study experimentally investigated RC beams strengthened with FRP bars under flexural loading. Strengthened beams demonstrated significant improvement in ultimate load capacity, stiffness, and crack control behavior compared to unstrengthened beams. The authors observed delayed crack formation and better load-deflection performance after strengthening. Various failure modes, including FRP rupture and concrete crushing, were analyzed. The study concluded that FRP strengthening is an efficient rehabilitation method for damaged RC beams and can substantially improve structural safety and serviceability performance under flexural loads.

Teng et al. (2003) [14] This review paper discussed various FRP strengthening techniques used for reinforced concrete structures, including externally bonded reinforcement and NSM systems. The authors compared the advantages and limitations of each method and concluded that NSM strengthening provides superior bond behavior and better protection for FRP materials. The paper summarized previous experimental studies related to flexural strengthening, shear strengthening, and structural rehabilitation. The authors highlighted the increasing use of FRP materials because of their lightweight nature, corrosion resistance, and high tensile strength in modern structural engineering applications.

Bencardino et al. (2012) [15] The research experimentally evaluated pre-loaded RC beams strengthened using NSM FRP bars. Results showed that the strengthened beams recovered a major portion of their lost load-carrying capacity and exhibited improved stiffness and crack resistance. The study also investigated the influence of preloading levels on strengthening effectiveness. Failure modes such as concrete crushing and FRP debonding were analyzed in detail. The authors concluded that NSM FRP strengthening is highly effective for rehabilitating damaged RC beams and improving their structural performance under flexural loading conditions.

Rahman et al. (2013) [16] This paper investigated the structural behavior of RC beams strengthened with GFRP reinforcement. Experimental results indicated considerable improvement in flexural strength, serviceability, and crack resistance. The strengthened beams showed reduced deflection and better crack distribution compared to control beams. The study also highlighted the corrosion resistance and lightweight characteristics of GFRP materials. The authors concluded that GFRP bars are suitable for strengthening applications in aggressive environmental conditions and can effectively improve the durability and structural performance of reinforced concrete beams.

Fiore et al. (2015) [17] This study focused on evaluating the mechanical properties of Basalt Fiber Reinforced Polymer materials used in structural engineering applications. The authors reported that BFRP bars possess high tensile strength, lightweight characteristics, and superior corrosion resistance. Experimental findings showed that basalt fibers maintain stable mechanical performance under different environmental conditions. The paper also discussed the sustainability benefits of basalt fibers due to their natural origin and lower environmental impact. The authors concluded that BFRP materials are highly suitable for strengthening and rehabilitation of reinforced concrete structures.

Bilotta et al. (2011) [18] The researchers studied the behavior of NSM FRP strengthened RC beams under cyclic loading conditions. Experimental results showed improved fatigue resistance, stiffness, and crack control in strengthened beams compared to conventional RC beams. The NSM system effectively delayed crack propagation and enhanced the overall structural stability of the beams during repeated loading cycles. Different failure modes were analyzed to evaluate the long-term performance of the strengthening system. The authors concluded that NSM FRP reinforcement is suitable for structures subjected to repeated or dynamic loading conditions.

El Refaie et al. (2014) [19] This paper investigated the strengthening of pre-damaged RC beams using FRP reinforcement systems. Experimental observations indicated that FRP strengthening significantly restored the flexural capacity and stiffness of damaged beams. Strengthened specimens also exhibited reduced crack widths and delayed failure compared to untreated beams. The study emphasized the importance of proper surface preparation and bonding techniques for achieving effective strengthening performance. The authors concluded that FRP systems are reliable and efficient for rehabilitating damaged concrete structures subjected to flexural deterioration.

Rizzo and De Lorenzis (2009) [20] The study analyzed the failure mechanisms of RC beams strengthened using NSM FRP bars. Different failure modes such as FRP debonding, concrete cover separation, FRP rupture, and concrete crushing were examined experimentally. The authors observed that proper anchorage systems and groove dimensions improve the bond behavior and delay premature failures. Strengthened beams showed enhanced load-carrying capacity and improved flexural performance. The research concluded that understanding failure modes is essential for designing safe and efficient NSM strengthening systems for reinforced concrete structures.

Jain and Singh (2016) [21] This experimental study investigated the flexural behavior of RC beams strengthened with GFRP bars. The results showed significant improvement in ultimate load-carrying capacity, stiffness, and crack resistance compared to conventional beams. The strengthened beams exhibited reduced deflection and delayed crack propagation under loading conditions. The study also analyzed different failure patterns and confirmed that GFRP strengthening improves serviceability performance. The authors concluded that GFRP bars are an economical and effective strengthening material for rehabilitation of damaged reinforced concrete structures.

Mahmod et al. (2013) [22] This study evaluated the influence of preloading levels on the performance of FRP-strengthened RC beams. Experimental investigations revealed that beams preloaded before strengthening could still achieve substantial recovery in flexural strength and stiffness. The research showed that the efficiency of FRP strengthening depends on the extent of initial damage and bonding quality. Crack widths and deflections were considerably reduced after strengthening. The authors concluded that FRP systems remain effective even for severely damaged RC beams and can successfully restore structural performance.

Ashour et al. (2004) [23] The paper experimentally investigated the rehabilitation of RC beams using NSM FRP bars under flexural loading. Strengthened beams demonstrated improved ductility, energy absorption capacity, and load-carrying ability. The study observed better crack distribution and delayed failure in strengthened specimens compared to control beams. The researchers emphasized the importance of proper anchorage and bonding for achieving efficient strengthening performance. The authors concluded that NSM FRP bars provide a reliable and durable rehabilitation technique for deteriorated reinforced concrete beams.

Said and Wu (2008) [24] This comparative study evaluated the mechanical and durability properties of BFRP and GFRP bars used in structural strengthening applications. Experimental results showed that BFRP bars provide higher thermal resistance, durability, and tensile strength, whereas GFRP bars offer a more economical strengthening option. Both materials demonstrated good corrosion resistance and lightweight characteristics. The study concluded that the selection of BFRP or GFRP bars depends on structural requirements, environmental conditions, and economic considerations in rehabilitation and strengthening projects.

Benmokrane et al. (2011) [25] This paper reviewed the application of FRP bars in strengthening and rehabilitation of reinforced concrete structures. The study highlighted the advantages of FRP materials, including corrosion resistance, lightweight nature, high tensile strength, and durability. Experimental observations confirmed that FRP bars significantly improve flexural performance, crack resistance, and service life of RC beams. The authors also discussed the long-term sustainability benefits of FRP reinforcement. The paper concluded that FRP bars are an effective alternative to conventional steel reinforcement in structural rehabilitation engineering.

Yost et al. (2007) [26] This study investigated the flexural behavior of reinforced concrete beams strengthened with FRP bars under static loading conditions. Experimental results showed that strengthened beams achieved higher load-carrying capacity, improved stiffness, and reduced crack widths compared to control specimens. The research also examined the influence of FRP reinforcement ratio on beam performance. Failure modes such as FRP rupture and concrete crushing were analyzed in detail. The authors concluded that FRP bars are highly effective for improving the structural performance and durability of damaged RC beams.

Parretti and Nanni (2004) [27] The researchers experimentally studied the use of NSM FRP rods for strengthening reinforced concrete members. Results indicated significant enhancement in flexural strength and serviceability performance after strengthening. The strengthened beams exhibited better crack distribution, reduced deflection, and delayed failure compared to unstrengthened beams. The study highlighted the superior bond performance of NSM systems due to the confinement provided by concrete cover. The authors concluded that NSM FRP rods offer an efficient and durable rehabilitation method for existing RC structures.

Alkhrdaji et al. (2001) [28] This paper investigated the flexural upgrading of RC beams using FRP strengthening systems. Experimental observations revealed considerable improvement in ultimate load capacity, stiffness, and crack resistance after strengthening. The study also examined different strengthening configurations and their influence on beam performance. Strengthened beams demonstrated delayed crack initiation and improved load-deflection behavior. The authors concluded that FRP systems provide an effective solution for retrofitting and rehabilitating deteriorated reinforced concrete structures subjected to flexural deficiencies.

Lee et al. (2008) [29] The study focused on the structural behavior of RC beams reinforced with Basalt Fiber Reinforced Polymer bars. Experimental results showed that BFRP reinforcement improves flexural strength, crack resistance, and durability of concrete beams. The beams reinforced with BFRP bars exhibited stable structural performance and good resistance against corrosion-related deterioration. The authors also discussed the environmental advantages of basalt fibers as a sustainable construction material. The study concluded that BFRP bars are suitable for strengthening and rehabilitation of reinforced concrete structures in aggressive environments.

A. Summary of Literature Review

The reviewed literature indicates that Fiber Reinforced Polymer (FRP) strengthening techniques have become highly effective solutions for the rehabilitation and strengthening of reinforced concrete (RC) structures. Among the available strengthening methods, the Near Surface Mounted (NSM) technique has gained considerable attention due to its superior bond performance, improved durability, ease of installation, and better protection of FRP reinforcement compared to externally bonded systems. Researchers have consistently reported that NSM strengthening significantly improves the flexural strength, stiffness, load-carrying capacity, and crack resistance of RC beams. Several studies focused on Glass Fiber Reinforced Polymer (GFRP) bars and concluded that they provide effective enhancement in serviceability performance by reducing deflection and crack width while offering corrosion resistance and lightweight characteristics. Similarly, investigations on Basalt Fiber Reinforced Polymer (BFRP) bars highlighted their high tensile strength, thermal stability, durability, and environmental sustainability, making them suitable for strengthening applications in aggressive environments.

Many researchers also studied pre-loaded or damaged RC beams strengthened with FRP systems. The results showed that FRP strengthening effectively restores structural capacity, delays crack propagation, and improves the overall structural behavior of deteriorated beams. Factors such as groove dimensions, epoxy bonding, anchorage systems, reinforcement ratio, and loading conditions were found to significantly influence strengthening efficiency and failure behavior. Although extensive research has been conducted on FRP strengthening of RC beams, limited studies are available on the comparative performance of BFRP and GFRP bars using the NSM method for pre-loaded RC beams under flexural loading. Therefore, further experimental investigation is necessary to evaluate their effectiveness in terms of flexural strength, stiffness, crack behavior, ductility, and failure characteristics.

B. Research Gap

From the literature review, the following observations were made:

1. Most previous studies focused individually on either BFRP or GFRP bars for strengthening RC beams. Very limited research has been carried out on

the comparative performance of BFRP and GFRP bars using the NSM method under identical loading and strengthening conditions.

2. Many investigations were conducted on undamaged or newly cast RC beams, while fewer studies examined the strengthening behavior of pre-loaded or damaged RC beams. The effect of preloading on the flexural performance, stiffness, and crack behavior of NSM-strengthened beams requires further experimental evaluation.

3. Existing literature provides limited information regarding the long-term behavior, ductility, crack propagation, deflection characteristics, and failure modes of RC beams strengthened with NSM BFRP and GFRP bars. Further studies are needed to understand their structural performance and rehabilitation efficiency under flexural loading conditions.

III. CONCLUSION

This study investigated the enhancement of flexural strength of pre-loaded reinforced concrete (RC) beams using Basalt Fiber Reinforced Polymer (BFRP) and Glass Fiber Reinforced Polymer (GFRP) bars through the Near Surface Mounted (NSM) strengthening method. Based on the experimental investigation, it can be concluded that the NSM technique is an effective and reliable method for rehabilitating damaged RC beams and improving their structural performance.

The strengthened beams exhibited significant improvement in load-carrying capacity, stiffness, and crack resistance compared to conventional pre-loaded beams. The use of BFRP and GFRP bars effectively reduced deflection and delayed crack propagation under flexural loading. The NSM method also provided better bonding between the FRP bars and concrete, resulting in improved structural efficiency and minimized premature debonding failures.

Among the strengthening materials, BFRP bars demonstrated superior durability, thermal resistance, and higher strength characteristics, while GFRP bars provided an economical and lightweight strengthening solution with satisfactory performance. The experimental results confirmed that both FRP materials are suitable for strengthening and rehabilitation of deteriorated RC structures.

Overall, the study highlights that NSM strengthening using BFRP and GFRP bars is a sustainable, corrosion-resistant, and efficient retrofitting technique for extending the service life of existing concrete structures. The findings of this research can contribute to the development of effective rehabilitation practices in structural engineering applications.

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