STM JOURNALS

Journal of
Polymer & Composites

ISSN: 2321-2810 (Online)
ISSN: 2321-8525 (Print)
Volume 14, Issue 1, 2026
DOI (Journal): 10.37591/JoPC

https://journals.stmjournals.com/jopc

Review JoPC

Mechanical Performance and Material Properties of Nsm CFRP Polymer System

G. Santhosh Kannan[1,*], M. HemaPriya[2], B. Vijaya[3], J. Faney[4]

Abstract

Near-surface mounting systems are an advanced embedded technique application of CFRP composites in which the efficiency of the structure is mostly dominated by polymer matrix properties and interface stress transfer mechanisms. This review presents a holistic materials-based perspective on the experiment, analytical, and numerical studies conducted on the NSM-CFRP composite system, specifically on the behavior of the epoxy adhesive, interfacial behavior of composite–substrate system, and related structure–property relationships. The literature suggested that even strain distribution and load capacity can be increased with embedded CFRP reinforcement due to the better confinement and the reduction in debonding of concrete cover and reinforcement as compared to externally bonded systems. From the literature the most influential parameters towards the modeling of the interface are groove geometry, adhesive stiffness and thickness, CFRP surface morphology, anchorage detailing, and polymer time dependent phenomena of creep, shrinkage, environmental degradation. Furthermore, contemporary interface modeling methods based on cohesive zone theories as well as novel data-driven methods, are evaluated in terms of their capabilities to simulate the evolution of interfacial damage and composite response [1]. To summarize, this review demonstrates that NSM-CFRP systems can be considered as embedded polymer composites with high performance, and thus with profound implications for polymer science, composite engineering and sustainable infrastructure restoration.

Keywords: Carbon fiber reinforced polymer (CFRP), embedded polymer composites, epoxy adhesive systems, interfacial bond mechanics, polymer–composite interfaces

INTRODUCTION

Carbon fiber-reinforced polymer (CFRP) composites are a type of advanced functional material that has been widely studied due to their high specific strength, corrosion resistance, and mechanical properties that can be tailored. Due to these attributes, CFRP-based systems have been the subject of numerous studies in the fields of polymer engineering, composite materials science, and multifunctional materials. One of the main areas of research in this applied composite systems is the interaction at the interfaces of polymer matrices, fiber reinforcements, and the host substrate, which influences the stress transfer, the longevity and the performance of the composite as a whole.

NSM CFRP strips, bars or laminates are placed into the cementitious host substrate along pre-cut grooves and are bonded with an adhesive glue [4]. Specifically, this type of composite configuration provides various inherent advantages including improved bond behavior and better anchoring, retardation of debonding compared to externally bonded laminates and better protection of the CFRP against external impacts. Therefore, the NSM

*Author for Correspondence
G. Santhosh Kannan
E-mail id: santhoshhrc@gmail.com

[1,4] Research Scholar, Department of Civil Engineering, Bharath Institute of Higher Education and Research, Tamil Nadu, India
[2]Assistant Professor, Department of Civil Engineering, Bharath Institute of Higher Education and Research, Tamil Nadu, India
[3]Professor, Department of Civil Engineering, Dr. MGR Educational and Research Institute Maduravoyal, Tamil Nadu, India

Received Date: December 16, 2025
Accepted Date: December 29, 2025
Published Date: January 07, 2026

Citation: G. Santhosh Kannan, M. HemaPriya, B. Vijaya, J. Faney. Mechanical Performance and Material Properties of Nsm CFRP Polymer System. Journal of Polymer & Composites. 2026; 14 (1): 311–319p.

technique tends to more fully exploit the tensile capacity of the CFRP, and an efficient embedded polymer composite system can be achieved, which is determined by the interfacial load transfer and adhesive behavior. The approach has been studied for a range of composite system configurations with various types of substrate geometries and loading condition [2].

Concerning CFRP application techniques, the near-surface mounted (NSM) method is a unique polymer-composite bonding system in which CFRP strips, rods or bars are inserted into a small groove, previously cut into the surface of the concrete and anchored with polymer (commonly epoxy) adhesives. This enclosed system leads to better confinement of the composite, results in a more even interfacial stress distribution and provides enhanced protection to the polymer reinforcement when compared to surface bonded systems. From the perspective of polymer science, NSM-CFRP systems are unique model systems to investigate structure-property and adhesive-composite as well as bond-slip interactions in mechanical loading and environmental conditions.

Recent investigations have gone beyond the applied research and addressed the basic problems like adhesive chemistry, groove dimensions, CFRP morphology and polymer creep, and their significance on load transfer mechanism and failure patterns in NSM-CFRP. In particular, novel experimental characterization, numerical modeling and data-driven analysis have offered even more profound insight into the response of the composite interface.

Nonetheless, inconsistency between the approaches for polymer materials characterization, for the interface modeling and for the durability testing are still found and they are impeding the progress of unified design and performance evaluation protocols.

Hence, in this review, a polymer composite based perspective is adopted to introduce the state of the art for the NSM-CFRP systems, focusing on the polymer composite constituents, interfacial mechanics and structure–property relationships. The objective is to identify key current advances and bottlenecks as well as to sketch out prospective research directions that could guide the development of highly reliable, long-lived and high-efficiency CFRP-polymer composite systems for future engineering applications [3].

Literature Review

Recently, several papers that add to the experimental database and with improved prediction models have been published in 2023 Subramaniam et al., 2023; Swamy and Nagamani, 2023; Chen et al., 2023 Muhammad et al., 2023 showing that the NSM-CFRP scheme is further enhanced. Jedrzejko et al. (2023) carried out a full scope investigation of NSM-CFRP systems enhancement, reporting that NSM bars possess a better performance than externally bonded strips in crack interception, especially in beams with large stirrup spacing. They stated that when groove depth was insufficient and / or long anchorage length was not supplied, debonding was usually preceded by cover spalling. In the same manner, Matteo, and De Felice (2023) studied the enhancement of NSM-CFRP composite systems using NSM CFRP laminates, proving that an increase of adhesive stiffness resulted in an improved load transfer efficiency, but also in a risk of brittle failure. The findings showed the importance of the groove shape and the stickiness of the surfaces in determining the behavior of the beams we embedded composite system.

Developments were made in 2024 especially for predictions based on modeling and machine learning. Their investigations demonstrated that groove depth, FRP area, and concrete compressive strength were the most influential parameters on the efficiency of composite performance evaluation. The model demonstrates good prediction capability, which implies that machine learning methods could be used to complement or improve traditional analytical methods in design. Shhabat et al. (2024) studied the healing of heat-damaged NSM-CFRP composite systems with NSM-CFRP strips, concluding that the technique successfully recovered in certain instances and even enhanced the initial (predamage) strength [6]. They showed that the embedded system perform better than the externally bonded FRP one under thermal exposure, validating NSM as an appropriate method for the structures. From a polycomposite perspective, these work highlight the dominant role of epoxy adhesive stiffness, groove confinement and CFRP surface morphology on the interfacial stress transfer and composite failure mechanisms.

Currently, the bond performance and its longevity have attracted more attentions of researchers. Zhao and Lin (2024) studied the bond-slip behavior of NSM CFRP strips. Their results highlighted the need of an epoxy system for quenching that can maintain the bond integrity during combined cyclic and environmental harassments. These novel results reveal that NSM-CFRP systems are very promising for reinforcing NSM-CFRP composite systems but there are still open issues concerning bond durability, anchorage reliability and the formulation and validation of homogenized design schemes suitable for engineering applications. From a polymer composite viewpoint this novel results represent the primary importance of epoxy adhesive stiffness and interface confinement in determining composite stress-transfer and failure.

Research Gaps in Embedded NSM-CFRP Polymer Composite Systems

In spite of the high interest for NSM-CFRP composite performance evaluation of NSM-CFRP composite systems, several research issues still need to be addressed to enable the formulation of general materials performance frameworks and to promote the implementation on the applied composite systems [9]. First, the existing majority of published research work on short-span beams subjected to monotonic loading, and very limited investigation has been performed about the behavior of NSM-CFRP systems when subjected to cyclic, fatigue, repetitive impact or multi-hazard events that simulate real applied loading conditions. Second, the long-term behavior of NSM-CFRP, including the effect of adhesive degradation, moisture transport, temperature changes, steel bar corrosion and sustained load, has not been sufficiently studied, which leads to uncertainty in durability and long-term composite response predictions. Third, there is a general absence of harmonised configurations, that is, composite performance evaluation systems with cementitious host substrate, adhesive type, CFRP shape (strips vs rods) and installation procedure vary significantly from study to study, and this diversity prevents standardised composite performance evaluation solutions or valid bond-slip models from being developed [5]. In addition, the interaction between NSM-CFRP and internal steel reinforcement, especially at high load levels which lead to debonding or cementitious host substratecracking, is not fully understood. Finally, there are few studies that provide full validation by means of numerical simulation as well as experimental testing at the system-level validation, which leads to the consequence that no robust, applied composite systems-applicable advice can be given to the composite system deployment are shown in Figure 1 a) and b).

Critical Analysis of Existing Studies

The majority of available research on NSM CFRP provides insightful results; however, they are performed in highly controlled environments, making the relevance of their application limited. Most experiments employ a small number of specimens and standard four-point bending arrangements and do not consider realistic structural features like continuous spans, cyclic loadings, variable supports, or issues related to composite system optimization. In addition, the majority of research is based on individual parameters, for example, groove depth, adhesive type or CFRP geometry, and do not consider the multi-factor interactions [8]. This presents challenges to developing generalizable results or accurate predictive models. Inadequate reporting of details of groove size, adhesive cure conditions, surface preparation and failure criteria also hinders comparison between studies.

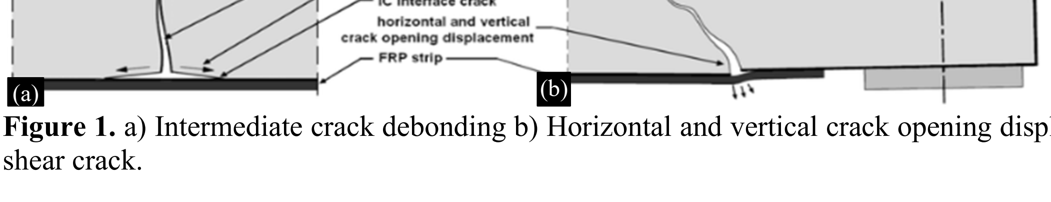

Figure 1. a) Intermediate crack debonding b) Horizontal and vertical crack opening displacement in a shear crack.

Table 1. Composition of cementitious host matrix used for composite interface evaluation.

Material	Weight (kg/m^3)
Cement	650
Silica sand	528
Coarse aggregate	770
Crush sand	264
Water	162.5

Although extensively used to understand the behavior, analytical, and numerical methods are usually based on idealized assumptions on materials and have limited experimental validity. Description of bond-slip relationships, adhesive constitutive models, and damage mechanisms are not always complete, and this has an influence on prediction capacity. The long-term performance is not sufficiently addressed in the literature, including aspects, such as durability, weathering, fatigue loading, and adhesive aging. On the other hand, practical aspects like workmanship, accuracy in groove-cutting and quality control at the site have hitherto been investigated very little systematically, which may be a source of uncertainty for the application. In general previous research provides encouraging findings, but there is a need for more holistic, uniform, and applied composite systems-based procedures to advance NSM-CFRP to reliable materials engineering implementation where explained in Table 1.

Mechanical Interaction Between NSM-CFRP Reinforcement and Steel Bars

In terms of composite interface, the embedded CFRP reinforcement, polymer adhesive and metallic reinforcement contact affects stress redistribution and the compatibility at the interfaces of the hybrid composite system. The response of an NSM embedded composite system beam is dependent on the properties of the CFRP and its end bearing-interaction with the steel reinforcement. When the load is increased, the dissimilar stiffness of steel and CFRP produces a nonuniform stress distribution, influencing the crack pattern and the mechanisms of the stress transfer along the bond. The concrete between the steel bars and the NSM strip becomes the primary force-interacting medium, and with its cracking will cause a loss of strain compatibility. For beams with higher steel ratios contribution of CFRP may be rendered ineffective by premature yielding or a decrease in tension demand. To know this relation is essential for the prediction of the flexural capacity and the choice of the optimum groove locations and CFRP cross-sections.

MATERIALS-ORIENTED REVIEW METHODOLOGY FOR NSM-CFRP POLYMER COMPOSITE SYSTEMS

In order To cover all full NSM-CFRP works, this review work was conducted in a pleasant systematic manner. Stage 1 was a search for journal articles, conference papers and technical reports published between 2000 and 2024 with consideration given to the most recent 10-year period due to the rapid development of FRP technology. Keywords including NSM CFRP, near-surface mounted composite performance evaluation, CFRP beams, FRP composite performance evaluation, and bond behavior of NSM systems were utilized to search the major scientific databases Scopus, Web of Science, ScienceDirect, ASCE Library, and SpringerLink. Additional backward and forward searching was conducted to ensure inclusion of relevant and seminal papers.

Following data collection, all papers were screened with the following a priori inclusion criteria: (i) experimental and/or numerical study on NSM-CFRP applied to NSM-CFRP composite systems; (ii) there must be a explicit description of the composite performance evaluation and testing procedures; and (iii) related to embedded composite system response. The following were excluded: letters to the editor, articles with poor methodology, insufficient data or not applicable to structural composite performance evaluation. To facilitate orderly comparison, the identified studies were grouped into the following topical areas: bond behavior, numerical modeling, durability, and failure mechanisms. Each article was carefully examined for aim, test variables, results, limitations, and clinical relevance. This hierarchical structuring contributed to the representation of equal distribution and less biased representation in addition to identifying recurring theme, research gaps and emerging trends in the NSM-CFRP composite performance evaluation technique and that is shown in Figure 2.

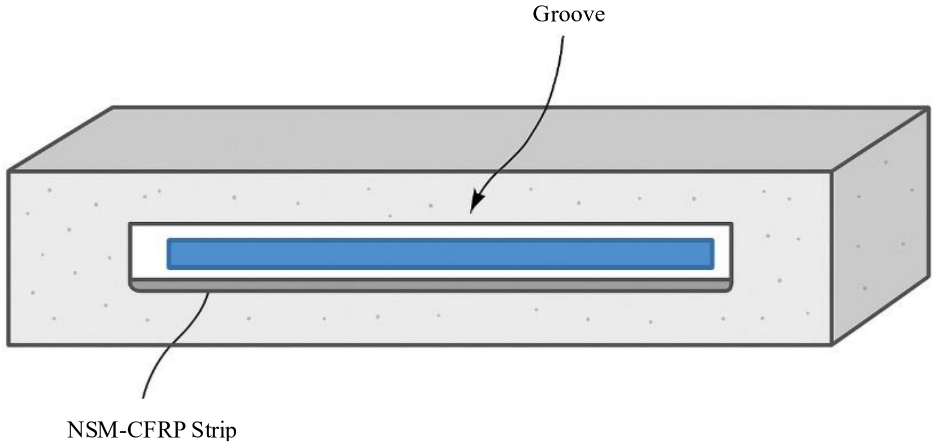

Figure 2. NSM CFRP polymer composite system.

Trends in Embedded CFRP Polymer Composite Systems

Recent NSM-CFRP composite performance evaluation studies have exhibited a clear tendency of enhancements in bond performance as well as total NSM-CFRP composite system composite performance evaluation effectiveness. One of the tendencies that can be observed is the optimization of groove shape, adhesive system, and CFRP profile to enhance the bond-slip resistance and to delay the initiation of debonding [10]. In the past five years, deviation in groove shapes, hybrid adhesives, and fiber-textured CFRP strips have been introduced, enabling better enhancement of mechanical interlocking and crack-bridging. A further significant achievement is the increasing application of prestressed NSM-CFRP systems, for which impressive gains in stiffness, deflection control and service load capacity were recorded in comparison to non-prestressed NSM applications. This trend is indicative of a shift towards composite performance evaluation based on performance rather than for the simple purpose of adding strength (, i.e., ultimate capacity).

With the progress in experiment, numerical methods and modern high-performance computing are used on a routine basis. Currently, high fidelity FE models, based on cohesive zone laws, incorporating nonlinear adhesive behavior and realistic geometrical bond interface features are used for failure prediction in mode I, mode II and mixed mode loading. Machine-learning predictive models have recently been developed as potential tools for parameters optimization and strength prediction. Furthermore, the attention of durability investigations has shifted to NSM-CFRP to be tested in situ under exposure to high temperatures, moisture cycling, chemical attack and adhesive degradation for long time. The applied composite systems is also moving towards methodology standardization with researchers developing unified bond models and design procedures that are envisioned to be included in future code. Summarizing, the state-of-the-art developments point towards a groundbreaking step in the successful implementation of reliable, durable, and code-compatible NSM-CFRP composite performance evaluation solutions for real-life engineering applications [7].

Comparative Evaluation of NSM vs Externally Bonded (EB) CFRP Systems

EB CFRP systems were extensively used in early composite performance evaluation applications because of their easy installation on the structure surface, but the service life of such systems is often limited by premature debonding failure and/or by environmental degradation. Since the CFRP is bonded to the concrete substrate, the strength and longevity of EB composite performance evaluation can be largely affected by the deterioration of the adhesive, inadequate surface treatment, and/or physical damage. This technique is highly dependent on the skill level of the individual applicator since the bond growth rate must be constant to have a constant bond.

Rather than being bonded to the surface of the structural elements, near-surface mounted (NSM) CFRP strips/rods are inserted into a pre-cut groove in the concrete cover, allowing for better confinement and possibly resulting in a more reliable bond. The confinement of the surrounding concrete provided a mechanical anchorage that led to an increased strain utilization, a delayed debonding, and an improved crack management in NSM systems [11]. NSM also has a superior resistance to moisture, temperature fluctuations and impact loads since the CFRP is embedded within the concrete shell. While the NSM method requires accurate groove cutting and a bit higher accuracy in installation, it usually offers more composite performance evaluation efficiency and long term durability than EB methods, thus becoming a more sustainable solution for composite performance evaluation of structures.

Parameters Influencing Composite performance evaluation Efficiency

The bond behavior, load transfer, and overall structural behavior are directly affected by these parameters, which are in turn influenced by several interrelated NSM CFRP system parameters. One of the influential parameters is the type of CFRP reinforcement, as strips, rods, and rectangular laminates have different bond-slip behavior. Rectangular strips usually have a larger bonded area, while circular rods have uniform normal and shear stresses and minimal stress concentration at the corners and chamfers. The type and the thickness of the adhesive are significant factors, as higher stiffness epoxy-based adhesives with an appropriate curing level increase the shear transfer, while an excessive adhesive thickness diminishes the interface and causes early debonding.

The groove size has a significant influence on the bonding capacity. Deep or well-sized grooves increase the anchorage, and retard the splitting of the cover; shallow and/or wide grooves act in the opposite manner, by focusing the stresses and by diminishing the efficiency of the composite performance evaluation. There is also an additional effect of concrete compressive strength on the behavior, since higher strength concrete provides better confinement and crack micro closure and allows higher bond formation. In a similar way, how much additional CFRP contributes to flexural capacity depends on the ratios of reinforcement in the existing RC section; low steel ratio beams are often found to benefit more under increased tension demands taken up by CFRP.

In the end, the nature of the applied load (static, cyclic, or fatigue) also influences the effectiveness of the composite performance evaluation system. NSM CFRP under monotonic static loading normally fully utilizes its tensile capacity; however, cyclic, and fatigue loadings may lead to premature failure of the adhesive, an increase in interface slip, and eventual degradation of the long-term effectiveness. Investigation on such interactions is fundamental to achieve dependable enhancement of NSM-CFRP systems and, consequently, to propose a National/Brown Envelope Application to the applied composite systems engineers [9,12].

Durability and Long-Term Response of NSM-CFRP Polymer Composite Systems

Environmental and mechanical exposures that degrade the quality of the adhesive and the substrate-bond interface play an important role in the long-term behavior of NSM-CFRP. Temperature and humidity can modify the bulk mechanical properties of epoxy adhesives through a softening effect at high temperature and/or a stiffness reduction at low temperature associated with moisture absorption. These changes decrease the bonding between the CFRP and the concrete and so lead to more slip and earlier degradation of the composite performance evaluation effectiveness. Freeze–thaw cycling is accelerated during freeze-drying due to the nucleation of microcracks in the concrete and the adhesive layers that lead to time-dependent reductions in confinement and bond performance [13].

Chloride attack is a major problem in the aggressive environment, especially for building materials in coastal areas or in contact with deicing salts. Although CFRP does not corrode, chloride ions may infiltrate the cementitious host substrate and potentially have an indirect effect on the NSM bond interface. Moreover, the epoxy adhesives creep under long-term load may result in a progressive strain and stress relaxation in the adhesive layer, which could have a negative impact on the long-term performance, especially in prestressed NSM applications where the CFRP is subjected to a continuous tensile load. The gradual loss of stickiness of the adhesive properties with the passage of time may also

ISSN: 2321-2810 (Online), ISSN: 2321-8525 (Print)

give rise to delays in debonding. Natural and hybrid polymer composite systems have been shown to enhance mechanical performance through optimized fabrication and drilling parameters [14–17]. Similar material-oriented approaches are increasingly being explored for strengthening and repair applications [18].

Fatigue resistance is important in such situations of repeated loading. Although early slip, crack initiation and widening adhesive debonding between ribbon and rod can occur as a result of cyclic loading and these phenomena are capable of reducing the effectiveness of reinforcement even prior to ultimate failure of the member. Studies have shown that the NSM technique has better fatigue performance than the EB technique due to better confinement and higher stress levels in the NSM reinforcement, but the long-term cyclic performance has not been well evaluated yet. In fact, the durability of NSM-CFRP systems depends not only on the intrinsic material properties, but also on the quality of installation, the level of environmental protection and long-term system surveillance to provide assurance of performance in the service environment of the embedded composite system structure. The bar chart compares the initiation loads of flexural and shear cracks and the ultimate load capacity for different NSM-CFRP strengthened specimens, showing a clear increase in ultimate load with improved strengthening configurations and the same is represented in Figure 3.

SUMMARY

This paper reviewed the current research results of near-surface-mounted (NSM) CFRP systems for the NSM-CFRP composite systems with a focus on the significant contributions, behavior characteristics and existing limitations. Due to the confinement from the cementitious host substrate, NSM consistently exhibits better bond uniformity, strain utilization, and long-term performance than that of externally bonded (EB) CFRP systems as reported in the literature. Considerable advances have been made in the understanding of the bond behavior and in the development of a suitable groove geometry, in the evaluation of several adhesive systems and in the influence of CFRP shape and dimensions. Substantial research results highlight that increasing trends is observed in more sophisticated modeling techniques as well as the prestressed NSM system, as it leads to higher structural efficiency.

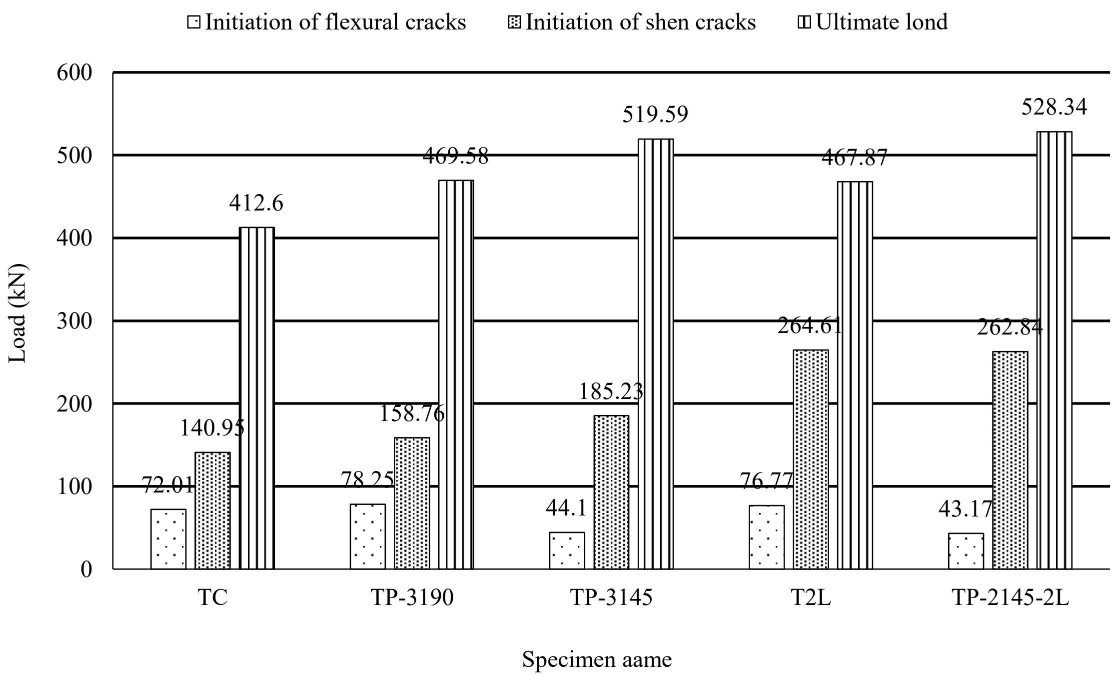

Figure 3. Comparative response trends of embedded CFRP polymer composite systems.

However, there still exist some essential deficiencies in long-term performance, fatigue behavior, environmental endurance, and realistic engineering application. Differences in the experimental technique and in the properties of the materials and application procedure have been reported in literature, so that it is not possible to directly compare the results among the various studies. In addition, multi-parametric interactions, the quality of the installation, and the validation in large scale of the applied composite systems, are not detailed considered. Collectively, the results of this study show that NSM-CFRP systems offer high potential for reliable NSM-CFRP composite system composite performance evaluation; however, further comprehensive studies are necessary To facilitate the adoption of this system for wide-scale application in the materials engineering implementation.

CONCLUSION

Through the lens of polymer composite materials, this article reviews the near-surface mounted (NSM) CFRP systems focusing on interfacial bonding behavior, structure–property relation and performance related parameters. The results obtained are in agreement with the embedded system promoting an improved confinement at the polymer–substrate interface leading to the better stress transfer and consequently to a higher exploitation of the tensile capacity of CFRP, and a more stable composite response than surface bonded system.

Considerable progress has been made on the understanding of the effects of the properties of epoxy adhesive, the geometry of the groove, the morphology of CFRP, and the prestressing technique on the behavior of the composite. The state–of–the–art analytical modeling, finite element simulation, and machine learning (ML) prediction methods have enhanced the knowledge of bond–slip and related failure modes.

These results illustrate the feasibility and potential robustness of NSM-CFRP systems as a high-performance polymer composite system in which maintaining interfacial integrity and durability is essential. Despite the integrated approach's extraordinary success in polyoxyehter engineering, it is not without its challenges proved in polymer engineering. Epoxy-based adhesive systems' durability on long-term, time-dependent creep of polymer, fatigue-induced damage of the interface, and effects of environmental exposure are yet to be adequately characterized. The development of polymer characterization techniques, testing procedures, and standards is hampered by the discrepancies noted among the various procedures.

The solution of such problems by a combination of experimental, numerical, and multiscale approaches will be a key element in bringing the NSM-CFRP systems to strong, application-ready polymer composite technologies. In general, NSM-CFRP systems exhibit good promise to be considered high-performance polymer composite system architectures. Further investigations in interfacial science, material durability, and structure–property optimization will be important in enabling their wider use in high-end composite engineering applications.

REFERENCES

1. Tworzewski P, et al. Composite performance evaluation of reinforced concrete beams using near-surface mounted (NSM) carbon fiber–reinforced polymer strips with additional anchorage. *Materials*. 2025;18(11). doi:10.3390/ma18112579.
2. Khol S, et al. Enhancement of NSM-CFRP composite systems using partial-length near-surface mounted (PLNSM) CFRP strips. *Int J Concr Struct Mater*. 2024;18:90. doi:10.1186/s40069-024-00727-3.
3. Issa S, et al. Composite performance evaluation and repairing of reinforced concrete T-beams exposed to high temperature using near-surface mounted carbon fiber–reinforced polymer ropes. *Engineered Science*. 2024;31:872. doi:10.30919/es8d872.
4. Hemapriya M, et al. Experimental investigation on reinforced concrete beams retrofitted with synthetic wraps. In: *Proceedings of the International Conference on Thermal Analysis and Energy Systems*. 2022. Available from: www.elsevier.com/locate/matpr

5. Fayed S, et al. Composite performance evaluation of NSM-CFRP composite systems using prestressed near-surface mounted CFRP rods. *Materials*. 2024;17(23). doi:10.3390/ma17235701.
6. Al-Zu'bi H, et al. Composite performance evaluation of reinforced concrete beams with variable compressive strength using near-surface mounted carbon fiber–reinforced polymer strips. *Fibers*. 2022;10(10):86. doi:10.3390/fib10100086.
7. Hemapriya M, et al. Investigation on NSM-CFRP composite systems embedded with hybrid fiber-reinforced polymer laminates at the flexural zone. *Mater Today Proc*. 2021. Available from: www.elsevier.com/locate/matpr
8. Al-Ameedee HS, Al-Khafaji HM. Improving the flexural behavior of NSM-CFRP embedded composite systems by near-surface mounting. *J Mech Behav Mater*. 2022;31(1). doi:10.1515/jmbm-2022-0070.
9. El-Hacha R, Gaafar M. Composite performance evaluation of reinforced concrete beams using prestressed near-surface mounted CFRP bars. *Compos Struct*. 2017;163. doi:10.1016/j.compstruct.2016.12.044.
10. Michałowska-Maziejuk D, Goszczyńska B. Effectiveness of NSM-CFRP composite systems using composite materials—an accelerated evaluation method. *Materials*. 2023;16(13):4847. doi:10.3390/ma16134847.
11. Abadel A, et al. Composite performance evaluation of deficient reinforced concrete deep beams using NSM-FRP systems: experimental and numerical investigation. *Mater Sci Pol*. 2024;42(1). doi:10.2478/msp-2024-0012.
12. Hemapriya M, et al. Experimental study on failure modes of NSM-CFRP externally embedded composite systems with multiple layers of FRP sheets. *IOP Conf Ser Mater Sci Eng*. 2021;2272:012022.
13. Aruchamy, et al. Enhancement of Mechanical Properties of Hybrid Polymer Composites Using Palmyra Palm and Coconut Sheath Fibers: The Role of Tamarind Shell Powder. BioResources 2025, 20(1), 698–724, doi:10.15376/biores.20.1.698-724.
14. Ganesan, K., et al. Optimization of Fabrication Parameters of Jute Fiber/Polyester Composites with Egg Shell Powder and Nanoclay Filler. Molecules 2020, 25(23), 5579, doi:10.3390/molecules25235579.
15. Karthik, A, et, al.Mechanical and drilling parameters of natural-fiber-based composites (Journal of Composites Science, 2025) – includes DOI:10.3390/jcs7040136. Journal of Composites Science 2025, 7(4), article 136, doi:10.3390/jcs7040136.
16. Malik et, al. Drilling Performance of Natural Fiber Reinforced Polymer Composites: A Review. Journal of Natural Fibers 2021, 19(12), 4761–4779, doi:10.1080/15440478.2021.2022562.
17. Zapris AG, et al. Innovative torsional performance evaluation of RC T-beams using NSM-FRP ropes. Proc Int Struct Eng Constr. 2024;11(2). doi:10.14455/ISEC.2024.11(2).STR-30.
18. Palanisamy, et, al.Tensile properties and fracture morphology of Acacia caesia bark fibers treated with different alkali concentrations. Journal of Natural Fibers, 2022. https://doi.org/10.1080/15440478.2021.2022562

