A Study on Literature of Strengthening of Beam Partial Replacement of Cement by GGBS & Fly Ash and Using CFRP Wrapping

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Abstract—In recent years, the construction industry has increasingly included Fibre Reinforced Polymer (FRP) as a means of reinforcing structures. This practise often involves utilising FRP in conjunction with other commonly used construction materials, including wood, steel, and concrete. Fiber-reinforced polymers (FRPs) provide a range of enhanced characteristics, including a high ratio of strength to weight, a high ratio of stiffness to weight, design flexibility, resistance to corrosion, high fatigue strength, and simplicity of application. Several researchers have conducted studies on the application of FRP sheets or plates as bonding materials for concrete beams. The utilisation of adhesive bonded FRPs for the purpose of enhancing structural integrity has been widely recognised as a successful technique applicable to various forms of concrete constructions, including columns, beams, slabs, and walls. The utilisation of Fibre Reinforced Polymer (FRP) materials for the purpose of external reinforcement of pre-existing concrete structures has been on the rise due to its advantageous properties, including non-corrosiveness, non-magnetism, and resistance to a wide range of chemical substances. Previous research has demonstrated that the application of externally bonded glass fiber-reinforced polymers (GFRP) can effectively augment the flexural, shear, and torsional strength of reinforced concrete (RC) beams. The utilisation of flexible glass fibre sheets has been seen to be highly advantageous in enhancing the structural integrity of RC beams. This is mostly due to their adaptable characteristics, simplicity of manipulation and application, as well as their exceptional tensile strength-to-weight ratio and stiffness. The utilisation of FRPs in the restoration of preexisting concrete structures has shown significant and rapid growth in recent years. Numerous studies have demonstrated the effective use of FRP materials for enhancing the structural integrity of concrete beams that exhibit deficiencies in flexural, shear, and torsional capacities. Regrettably, the existing Indian concrete design standards, commonly referred to as IS Codes, do not incorporate any rules pertaining to the reinforcement of structural elements in terms of flexural, shear, and torsional strengthening utilising FRP materials. Due to the lack of design standards, research and industry collaborated to explore and advocate for FRP in structural restoration, notably flexural, shear, and torsional rehabilitation. Carbon, aramid, or glass fibres are mixed with a polymeric matrix like thermosetting resin to make FRP. Fibers are the main load-bearing component of FRP.

Indexed Terms— Fibre-Reinforced Polymer (FRP), Carbon Fibre Sheets, Ultimate Load.

I. INTRODUCTION

To mitigate the issues arising from the corrosion of steel reinforcement in concrete structures, scholarly investigations have indicated the viability of substituting steel reinforcement with fibre reinforced polymer (FRP) reinforcement. The degradation of the steel reinforcement within reinforced concrete (RC) constructions has a detrimental impact on the mechanical properties of both the steel and the concrete materials. The corrosion of a steel reinforcing bar leads to a reduction in its cross-sectional area, which in turn compromises its structural integrity. The corrosion of steel reinforcing bars causes the concrete to weaken as fractures occur in the concrete cover due to the expansion of corrosion products. The rehabilitation of infrastructures is a well-established practise, with several projects having been implemented globally in the last twenty years. One method employed to enhance the structural integrity of reinforced concrete elements is the application of steel plates externally, utilising two-component epoxy adhesives. Through this approach, it becomes feasible to enhance the mechanical efficacy of a structural element. The extensive application of this technique in diverse architectural and engineering contexts, encompassing structures such as buildings and bridges, has substantiated its efficacy and practicality. Notwithstanding this fact, the plate bonding process exhibits several drawbacks attributable to the utilisation of steel as a strengthening material. The primary disadvantages associated with steel include to its substantial weight, which poses challenges in terms of on-site plate handling, as well as its susceptibility to corrosive conditions. In addition, steel plates possess.

II. OBJECTIVE

1. For the present research, the following objectives have been set.
2. To evaluate the effectiveness of the external GFRP wrapping technique in retrofitting of built RC Beam.
3. Determine the maximum load-bearing capacity of the specimens retrofitted using the FRP wrapping technique with respect to their flexural strength.
4. Comparison of the results obtained from the control RC beam and retrofitted RC beams GFRP wrapped.

III. METHDOLOGY

This chapter contains a thorough introduction to the technique of enhancing the strength of reinforced concrete (RC), prestressed concrete, and steel elements through the utilization of externally affixed steel plates or fiber reinforced polymer (FRP) composite sheets and plates. This is accomplished through a thorough analysis of the most significant research studies recorded in the literature. Furthermore, there is a dedicated part that focuses on enhancing the resistance of reinforced concrete elements against shear forces by utilizing fiber-reinforced polymer (FRP) plates and sheets. Nevertheless, the utilization of external plating as a method of reinforcement has only become feasible due to the advancement of appropriate adhesives. Therefore, it is necessary to consider the many types of adhesives that can be employed for bonding external plates and their specific needs for this purpose. This text presents a concise overview of surface preparation procedures that can be applied to FRP and concrete adherends, considering previously conducted plate bonding tests.

IV. LITERATURE REVIEW

Macdonald (1978) and Macdonald and Calder (1982) conducted experiments involving four-point loading tests on reinforced concrete beams with steel plates. The beams had a length of 4900mm. The beams were utilized to gather data for the suggested reinforcement of the Quinton Bridges. The construction involved the utilization of two different types of epoxy adhesives, with two plate thicknesses measuring 10.0 mm and 6.5 mm. As a result, the width-to-thickness ratios were 14 and 22, respectively. Furthermore, a plate lap-joint was integrated at the midpoint of the beams. It was noted that in each case, the beams experienced failure at one end because of horizontal shear occurring in the concrete adjacent to the plate of steel. This failure began at the end of the plate and led to an abrupt separation of the plate from the concrete, while the concrete remained attached, up to around the middle of the beam. The influence of the outer plate on crack control and stiffness was determined to be significantly more noticeable. The weights required to cause a crack width of 0.1mm were increased by 95%, resulting in a noticeable reduction in the deflections under this load. Post-cracking stiffness increased 35% to 105%, depending on adhesive type and plate size. The TRRL conducted a more extensive study on this work. Test beams were four-point bent. The beams were either coated as-cast or after a 0.1mm crack width load. An investigation was conducted to examine the impact of increasing the width of the plate while keeping its cross-sectional area constant. The study revealed that the load/deflection curves of the plated as cast and pre-cracked beams were comparable, indicating the efficacy of external plating in enhancing structural strength.

The RC beams measuring 3700mm in length were subjected to bending tests carried out by Ladner and Weder, (1981). The study focused on the plate's width-to-thickness (b/t) ratio, while keeping the plate's cross-sectional area constant. The exterior plate extended through and beyond the beam supports without making direct contact, covering a distance that ensured the bonded area 480 cm2 remained consistent for each plate width. The exterior plate was not adhered to the concrete beam except in the anchorage locations located beyond the supports. The findings unequivocally demonstrated that thin plating exhibited superior efficacy compared to thick narrow plating, as documented in the conducted tests.

Nevertheless, it is believed that the stress levels at the ends of the steel plate are far higher than those resulting from basic elastic analysis by Macdonald (1982). Due to plate-concrete stiffness mismatches, beam ends experience shear and normal stress concentrations when flexed. The adhesive layer must be deformed significantly to fix this mismatch. The sudden transition from uncoated to plate-reinforced components usually happens in a high-shear, low-bending moment location. Variations in bending moment and deformation in the adhesive layer cause axial force at the exterior plate edge. This causes high bond tensions at the adhesive plate-adhesive concrete contacts. These stresses might potentially reach critical levels, ultimately causing failure. Externally strengthened beams' plate end stresses depend on the plate reinforcement's shape, the adhesive's technical properties, and the concrete beam's shear strength (Swamy and Mukhopadhyaya, 1995). Biaxial tensile stress results from peak peeling, shear, and bending forces at the plate end. This extends the plate end crack horizontally to the internal steel layer.

Utilizing larger and thicker steel plates enhances the structural advantages of external plating. To prevent separation or restrict certain sections, an alternate approach would be to incorporate plate anchorage mechanisms. Jones et al. (1988) conducted theoretical and practical investigations on the issue of anchorage at the extremities of steel plates. An experimental study was conducted on a set of 2500mm long reinforced concrete beams, which were reinforced with 6.0mm thick steel plates bonded with epoxy. The purpose of the study was to examine various methods of anchoring the plates at the ends of the beams. One configuration involved using four bolts with a diameter of 6.0mm at each end of the plate. These bolts went into the plate to a depth of 75mm. Additionally, different sizes of angle plates were tested. One of these angle plates covered the entire shear span. The results were compared to those of a beam that had a single unanchored steel plate with a b/t ratio of 21. This beam failed suddenly when the plate separated at a load lower than that of the un-plated control beam. The analysis determined that the mooring detail had no noticeable effect on the deflection performance of the beams. While the introduction of bolts did not eliminate debonding, it effectively prevented complete detachment and led to strength improvements of up to 8% compared to the beam without plates. The adhesive anchor plates demonstrated superior adhesive properties.

The plating of the beam enhances its effectiveness by enabling the tensile plates to yield and reach their maximum theoretical strength, resulting in a 36% increase compared to the un-plated beam. The ductility of the beams approaching the ultimate load was also observed to be influenced by the anchorage detail. The beams, without support, experienced abrupt failure with minimal or no ability to deform. All the beams with bolts or anchor plates exhibited comparable ductility, with a minimum level equal to that of the un-plated control.

The flexibility of the plated beams was greatly improved, as stated by Jones et al. (1988), by the introduction of bolts with a diameter of 15 mm that were inserted halfway into the beam. On the other hand, their influence on the maximum load was not particularly significant. Furthermore, it was demonstrated that the improvement in ductility that was brought about by the incorporation of bolts decreased as the thickness of the plate increased. Since diagonal shear cracks in the shear spans were the root cause of the failure in this instance, the end anchoring was rendered incapable of preventing the beams from failing prematurely. The application of bonded steel plates for in situ rehabilitation or upgrading of reinforced concrete (RC) beams has been empirically demonstrated to effectively manage flexural deformations and crack widths. Furthermore, it enhances the load-carrying capability of the member under service load, particularly under ultimate circumstances. It is widely acknowledged as an efficient, convenient, and cost-effective approach to enhancing structural performance. Nevertheless, despite the shown efficacy of the procedure, it also entails drawbacks. Due to the lack of concrete protection, the plates are susceptible to corrosion, which can negatively impact the bond strength and ultimately result in the collapse of the strengthening system. There is still uncertainty regarding the long-term strength and the impact of corrosion. To reduce the risk of corrosion, it is necessary to remove any concrete contaminated with chloride before bonding. Additionally, the plates must undergo meticulous surface preparation, storage, and the use of priming systems that are resistant to corrosion. Following the installation, it is necessary to regularly assess the integrity of the primer, which adds an additional maintenance responsibility to the structure. The plates are commonly prepared through the process of grit blasting, which, if a minimum thickness of around 6mm is not enforced, might result in distortion.

In 1980, it was proposed that fiber reinforced polymer (FRP) sheets could be a better option than steel plates for strengthening reasons, to overcome the constraints of steel plate bonding (Meier and Kaiser, 1991). Fiber-reinforced polymers (FRPs), in contrast to steel, are resistant to electrochemical degradation and can endure the corrosive effects of acids, alkalis, salts, and other harmful compounds over a wide range of temperatures (Hollaway, 1993). As a result, there is no need for corrosion-resistant systems, which makes the preparation before bonding and maintenance after installation less difficult compared to steel. The introduction of reinforcing fibers at specified positions, with a desired volume percentage and orientation inside the matrix, enables the achievement of optimal efficiency. This allows for the customization of composites to meet specific shape and specification requirements. The resulting materials are non-magnetic, non-conductive, and have excellent fiber-direction specific strength and stiffness at a lower weight than steel. As a result, they are easier to transport and handle, require less falsework, may be used in restricted access areas, and do not burden the structure after installation. Long, unbroken sections of fiber reinforced polymer can be easily made and rolled to the construction site because to their flexibility. Consequently, the installation process avoids the incorporation of joints. Except for glass fiber composites, FRPs often demonstrate exceptional fatigue and creep characteristics and need lower energy per kilogram for production and transportation compared to metals. Due to its simpler installation method compared to steel, there should be less interruption on the site, resulting in faster and more cost-effective reinforcement.

The advantages of using FRP materials instead of steel in plate bonding applications are evident. The limitations include the inability to adhere well to uneven surfaces, leading to potential plate peeling. Additionally, there is a risk of brittle failure modes as identified by Swamy and Mukhopadhyaya in 1995. Furthermore, the material cost of fiber composites is significantly higher, ranging from 4 to 20 times the cost of steel per unit volume. In a rehabilitation project where material costs never exceed 20% of the total project cost, installation savings can offset higher material costs (Meier, 1992). Peshkam and Leeming (1994) studied the economic viability of FRP plate bonding bridge reinforcement. When directly comparing steel plate bonding to a normal application, although the cost of materials will be higher, there will be a decrease in labor and equipment expenses, shorter construction periods, and enhanced durability. Empirical evidence demonstrates that a little 2 kilograms of FRP has the capability to substitute a substantial 47 kg of steel while maintaining equivalent strength. Both materials have identical installation prices, but when considering factors such as traffic management, traffic delay, and maintenance expenses, using FRP results in a 17.5% cost save compared to steel. In certain scenarios, the usage of steel plate bonding may not be feasible due to the significant level of chloride contamination present in the concrete. FRP can be employed in such instances to circumvent the necessity of demolishing and replacing the structure. Peshkam and Leeming (1994) conducted a cost analysis comparing the replacement of bridges with the strengthening method using FRP. The study indicated potential savings of 40%. These cost comparisons were made before the assessment of actual manufacturing and installation costs and were based on the most precise estimations available. Upon further examination, the assessment of the bidding procedure for actual installation projects has indicated that CFRP plate bonding is highly competitive with steel plate bonding in terms of initial expenses, even before considering future maintenance costs in the overall calculation of life cycle expenses.

Composite materials offer a high degree of adaptability, making them a practical substitute for steel plates in reinforcement applications, leading to cost savings in both the short and long term. According to Meier and Winistorfer (1995), steel is the best choice for applications with minimum corrosion risk and strengthening lengths less than 8m. Nevertheless, recent study conducted by other scholars (ROBUST) and cost trends suggest that this stance is evolving, with signs showing FRP is more cost-effective than steel regardless of the length. This is particularly true in the context of building construction; however, the thickness of the plate may also be significant in terms of aesthetics. Fiber composites are a more appealing option in situations where corrosion, needed strengthening length, and on-site handling are particularly important, such as in bridge rehabilitation applications.

There have been concerns raised about the behavior of FRP reinforced members when they are subjected to fire. EMPA in Switzerland conducted a series of tests comparing the performance of steel and CFRP plated beams under exceptionally high temperatures (Deuring, 1994). Upon examination, it was discovered that a steel plate became separated within a few minutes of being exposed. In contrast, the CFRP laminates experienced a gradual reduction in their cross-sectional area owing to surface burning, resulting in a steady decrease in the member's stiffness. Eventually, the CFRP laminates detached completely after more than an hour. The better behavior seen is a direct result of the composite's low thermal conductivity. Moreover, the separation of a substantial steel plate from a structure, regardless of the cause, poses a significantly higher risk compared to a lightweight FRC material. Tabor (1978) and Hollaway (1993a) examine several aspects of the impact of fire on resin composites.

For reinforcement purposes, one may contemplate the utilization of composites composed of glass, aramid, and carbon fibers. Glass is commonly used as a reinforcing fiber due to its cost-effectiveness and widespread availability. Carbon fibers withstand moisture, solvents, bases, and weak acids and can be directly exposed to concrete (Santoh et al., 1983). Composite materials made from these components are lightweight, stronger than steel, and stiffer than glass and aramid composites. For instance, to attain the equivalent tensile stiffness with the same fiber volume fraction, laminates made from glass fiber need to be three times thicker compared to CFRP laminates. CFRP has exceptional fatigue characteristics and an extremely low (or even negative) linear coefficient of thermal expansion in the direction of the fibers. Non-destructive testing, such as infrared inspection, can be used for quality assurance in the field when CFRP laminates are utilized. However, this method is not applicable to steel plates. This method enables swift and precise assessment of the efficacy of the reinforcement efforts. Carbon composites, despite their higher price, provide superior qualities for enhancing structural strength.

The EMPA in Swiss has been at the forefront of innovating the utilization of FRP materials as a replacement for steel in plates bonding applications. The initial testing of reinforced concrete beams consisted of applying a four-point loading arrangement. The beams used in the experiments had lengths of either 2.0 m (Meier, 1987; Kaiser, 1989) or 7.0 m (Ladner et al., 1990). The reinforcement was accomplished by employing pultruded carbon fiber epoxy laminates with a thickness of up to 1.0 mm. These laminates were bonded using the same epoxy adhesives that were previously utilized in the steel plating work conducted by Ladner and Weder in 1981. The ultimate load for the 2000mm length beams was nearly twice as high as that of the unplated control beam. However, it is important to note that these beams were constructed with a minimal amount of internal steel, resulting in a relatively low strength for the unplated beam. For the 7000mm long beam, when a 1.0mm CFRP laminate was added, the ultimate load increased by approximately 22% (Ladner and Holtgreve, 1989). Nevertheless, the eventual deflection for both beam lengths was significantly decreased, despite the assertion that there was still adequate rotation to anticipate imminent failure.

Deblois et al. (1992) investigated the application of longitudinal and transverse GFRP sheets to improve flexural strength. Following the reinforcement, a set of RC beams measuring 1000mm in length underwent testing. The utilization of bidirectional sheets led to a maximum load enhancement of 34%, while the application of unidirectional GFRP resulted in a more modest rise of 18%. The writers of this chapter find the conclusion to be surprising and highlight that the FRP material employed was GFRP. The load capacity of the beam was enhanced by 58% with the supplementary adhesion of bidirectional Glass Fiber Reinforced Polymer (GFRP) to its sides, in conjunction with the use of unidirectional sheets. To further the study, Deblois et al. (1992) affixed a bidirectional Glass Fiber Reinforced Polymer (GFRP) sheet to the underside of a 4100mm long Reinforced Concrete (RC) beam using epoxy bonding. In addition, bolts were employed as supplementary anchorage at the extremities of the plate. The maximum load exhibited a 66% increase compared to the unplated control beam. It was observed that the use of GFRP in all tests resulted in a decrease in the ductility of the beam.

The investigation found that all reinforced beams had better strength and stiffness than untreated examples. Maximum load-carrying capability increased 230%. The true increase depends on the beam's internal strengthening before plating. The heightened rigidity led to an augmented load at the point of initial cracking, while significantly reducing the material's ability to deform before failure. Cracks spread throughout a large percentage of the test span after the initial crack. Even near maximum load capacity, most fractures were thin. All failures were abrupt and devastating, with a quick fracture from the area under strain to the point of load and concrete covering separation along the reinforcing material under tension. The form of failure has been observed in the steel plating work, as previously indicated. The tapering of the plate end, whether in plan or section, did not seem to have any impact on the flexural performance or failure mode for the analyzed examples. The beams that were pre-cracked before bonding exhibited comparable performance to the other test beams, demonstrating the efficacy of the plate bonding procedure for repair, like what was observed with steel plates. All plate configurations except those with laminates attached to the beam length and secured by reaction at the supports had constant load deflection. This arrangement exhibited enhanced strength compared to the other plated beams. It was determined that the ultimate loading capacity of the system had been attained for these specific beams and plates, with the shear capacity of the concrete beams being the governing factor.

The University of Surrey conducted a parametric analysis on flexurally strengthened reinforced concrete beams utilizing glass fiber reinforced polymer joined plates (Quantrill et al., 1995). The study examined the effects of different concrete strengths, pultruded composite plate areas, and aspect ratios (b/t). Steel plating applications with thick, thin plates with aspect ratios under 50 have been connected to brittle failure mechanisms. Therefore, the study examined the ratios of 38 and 67. In these tests, the impact of the b/t ratio was specifically examined by keeping the plate's cross-sectional area constant. The studies demonstrated that plating can significantly improve both the strength and stiffness of reinforced concrete elements, albeit at the cost of reduced ductility during failure. Compared to the unplated component, the more robust concrete had the greatest strength increase, while the plate aspect ratio had no effect.

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