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STUDY ON SHEAR STRENGTHENING OF BEAMS AIDED BY GEOPOLYMER

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Abstract: Strengthening beams is a crucial aspect of structural engineering, aiming to enhance load-bearing capacity and overall durability. Various methods are employed for this purpose, each tailored to the specific needs and conditions of the structure. One common approach involves affixing steel plates or fiber-reinforced polymers to the beam, effectively bolstering its flexural strength. External post-tensioning, concrete jacketing, and prestressing are techniques that introduce additional forces or materials to improve structural performance. Fiber reinforcement in concrete mixes and grouting injections can enhance tensile strength and address existing vulnerabilities. In this paper we discuss how we can increase the shear strength of beams using prefabricated geopolymer panels placing on the concrete beam surface by anchor bolts with particular spacing.

I.INTRODUCTION

Reinforced concrete structures often require strengthening due to aging, environmental damage, changes in usage, structural issues, outdated design standards, or construction shortcomings. This strengthening is crucial to meet increased load demands, adhere to contemporary safety codes, and reduce the risk of progressive collapse. Innovative methods, such as geopolymer mortars and fiber reinforcement, are employed to enhance structural performance, durability, and safety. These approaches not only address existing vulnerabilities but also contribute to more sustainable and resilient construction practices, ensuring structures remain adaptable and secure in the face of evolving needs and challenges. The geopolymer mortar panels represent an innovative approach to construction materials, employing geopolymers as a substitute for conventional Portland cement binders. Geopolymers, synthesized from aluminosilicate materials like fly ash or metakaolin and alkaline activators, present a sustainable alternative with lower carbon emissions. These panels find application in constructing walls, facades, and structural elements. Notable for their reduced environmental impact, geopolymer mortar panels leverage industrial by-products, contributing to a more sustainable building industry. Beyond environmental considerations, these panels offer high strength, durability, and resistance to chemical corrosion, making them suitable for diverse construction scenarios. Their fire resistance, lower shrinkage, and potential for rapid setting add to their appeal. Despite these advantages, challenges related to cost, material availability, and standardization persist, necessitating ongoing research and development. When integrating geopolymer mortar panels, adherence to local building codes, rigorous testing, and engineering scrutiny remain essential for ensuring structural integrity and performance.

Index Terms -Geopolymer, Concrete Beams, Shear Strengthening, Mortar panels

II. BACKGROUND STUDY

Ahmad L. Almutairi , Bassam A. Tayeh , Adeyemi Adesina , Haytham F. Isleem , Abdullah M Zeyad[1] This study explores the environmental aspects of sustainable development in the construction industry, focusing on the utilization of secondary raw materials and recyclable materials in new structures. The study emphasizes the shift towards geopolymer concrete as an alternative to Portland cement, driven by the need to reduce greenhouse gas emissions. Geopolymer concrete offers an 80% reduction in carbon dioxide emissions and decreased raw material usage. The paper focuses on various elements of geopolymer concrete, including precursors and their applications, discussing the environmental impacts and real-world applications for infrastructure construction. It highlights the strength improvements in geopolymer concrete with the inclusion of materials like Ground Granulated Blast Furnace Slag (GGBS), Silica Fume (SF), and Rice Husk Ash (RHA). Additionally, the review explores the use of geopolymer coatings for marine environments, providing sustainable protection to concrete structures. Overall, it involves information about the potential of geopolymer Material used in concrete for enhancing sustainability in construction practice.

Christian Escrig ,Lluís Gil ,Ernest Bernat-Maso , Francesc Puigvert [2] This research focuses on the application of textile- reinforced mortar (TRM) as a shear strengthening solution for reinforced concrete (RC) beams, addressing limitations of other methods. Four types of TRM are investigated, evaluating their mechanical performance and failure modes compared to previous formulations for fiber-reinforced polymers (FRP) and TRM. The study introduces new methodologies to assess bonding behaviour and increment in flexural toughness. Results indicate a substantial increase in shear resistance (average of 36%) and enhanced flexural toughness for all strengthened beams, achieving ductile failure instead of the brittle failure observed in unstrengthened beams. The effectiveness of TRM systems is attributed to bonding performance, with PBO textiles showing superior performance in shear resistance and flexural toughness. Analytical approaches based on FRP standards and TRM strengthening systems are compared, revealing conservative tendencies in FRP predictions and better accuracy with TRM formulations. The research proposes an analytical method based on TRM effective strain for estimating shear capacity contribution. However, further research is suggested to refine TRM responses and address debonding concerns between mortars, concrete substrate, and textile matrix in shear strengthening applications.

Ekaputri, J.J , Fujiyama C., Chijiwa N, Ho, T.D and Nguyen, H.T.[3].This paper highlights the advantages of incorporating PolyVinyl Alcohol (PVA) fibers to enhance the mechanical properties of class F fly ash-based geopolymer concrete. The activator employed in this study consisted of a combination of 8M sodium hydroxide and sodium silicate, with variations in the mass ratio of Na2SiO3 to NaOH at 1.5, 2.0, and 2.5. Cylindrical specimens of 100 mm diameter and 200 mm height were prepared to assess compression strength, splitting, and elastic modulus. PVA fibers were introduced into the geopolymers at concentrations of 0.4%, 0.6%, and 0.8% by the total concrete volume. The investigation revealed that the mixture with an alkali ratio of 1.5 and a PVA fiber content of 0.4% exhibited optimal workability. The highest strength was achieved in a mixture with alkali activator ratios of 1.5 and 0.6% fiber addition. Workability concerns and the orientation of fibers within the concrete emerged as pivotal factors influencing the overall properties of the geopolymer concrete. This study provides valuable insights into the synergistic effects of PVA fibers and alkali activator ratios, offering practical considerations for improving the performance of fly ash-based geopolymer concrete.

Hai Yan Zhanga , Jia Yanb , Venkatesh Kodurc , Liang Caod [4] This paper presents the findings of static load tests on ten reinforced concrete beams, examining the effectiveness of shear strengthening using textile-reinforced geopolymer mortar (TRGM). The study investigates various parameters, including the number of textile layers, geometry, adhesive type, and steel strip anchorage, in relation to shear capacity enhancement. Results indicate that TRGM significantly improves shear capacity, with a 47.1% and 105.9% increase for one and two layers, respectively, compared to the un-strengthened beam. Incorporating steel strip anchorage further enhances shear capacity by 14.7–20.6%. Despite TRGM's lower efficacy (50%) compared to resin-based counterparts, its promising attributes such as superior fire resistance, corrosion resistance, and weatherability make it a viable solution for retrofitting concrete structures. The effective strain in TRGM-strengthened beams is comparable to or higher than that in beams strengthened with ordinary textilereinforced mortar (TRM). The study proposes a modified model for calculating shear capacity in TRGM- strengthened beams, showing good agreement with test results. This comprehensive exploration establishes TRGM as a promising material for enhancing the structural performance of reinforced concrete beams.

Kai-Di Peng, Jun-Qi Huang d, Bo-Tao Huang , Ling-Yu Xu c, Jian-Guo Dai[5] This study provides a pioneering examination of the shear behavior in RC beams strengthened with a small-diameter CFRP bar- reinforced geopolymer matrix (FRGM) system. Twelve RC beams, incorporating various factors such as bonding methods, matrix types, CFRP bar alignment directions, FRGM layer configurations, and shear span-to-depth ratios, were prepared and tested.Notably, double-side FRGM layers demonstrated a significantly higher strengthening efficiency (1.9 times that of the reference beam) compared to single-side layers (1.2 times). The geopolymer-bonded layer exhibited a load capacity similar to its epoxy- bonded counterpart (approximately 98%). The inclusion of steel fibers in the geopolymer matrix further restrained shear cracks and enhanced shear capacity. The study also proposes a theoretical analysis method for predicting the shear capacity of FRGM- strengthened RC beams.

R Irmawaty , Fakhruddin, and Muthmainnah [6] This paper investigates the shear behavior, crack patterns, and failure modes of reinforced concrete beams strengthened with geopolymer and Portland cement mortar panels. The study involves specimens with specific dimensions, and the static monotonic loading test indicates a significant increase in maximum load for beams strengthened with geopolymer (34.98%) and Portland cement mortar panels (29.54%) compared to the control beam. The addition of panels alters the behavior of reinforced concrete beams, rendering them more ductile and influencing crack patterns and failure modes, with shear failure in CB beams and flexural failure in mortar panel-reinforced beams.

Rita Irmawaty , Fakhruddin , Januarti Jaya Ekaputri [7] The study provides information about the effectiveness of geopolymer-mortar panels (GMPs) in enhancing the shear capacity of reinforced-concrete (RC) beams. Employing a 15 mm thick prefabricated GMP anchored with mechanical anchors, the research explores anchor-bolt spacing, wire mesh presence, and binding material types. Results indicate significant shear capacity improvement ranging from 14.1% to 34.9% in GMP-strengthened beams compared to the unstrengthened counterpart. Notably, the study highlights a shift from brittle to ductile failure in beams with optimal anchor bolt spacing (200 mm) and wire mesh. The GMP emerges as a promising alternative for shear-strengthening RC beams due to its high strength and ductility. The analytical model based on the simplified-modified-compression-field theory aligns well with experimental results, supporting GMP's efficacy. Further analysis of shear-strengthened beams and comparisons with Portland- cement-mortar panels and a control beam emphasize the influential role of wire mesh over anchor bolt spacing. The study further agrees that GMP can prevent shear failure with adequate bolt spacing and wire mesh, offering flexibility in building applications.Additionally, the minor impact of binding materials suggests GMP as a viable alternative material for strengthening panels, affirming its potential contribution to advancements in structural engineering practices.

Saranya P, Praveen Nagarajan, A.P. Shashikala [8] This study explores the application of binary geopolymer concrete (GPC) using Ground Granulated Blast Furnace Slag (GGBS) and dolomite as source materials, emphasizing early-stage compressive strength. Steel fibers were added to enhance ductility, and both experimental and numerical investigations were conducted on steel fiberreinforced geopolymer concrete (SFGPC) beams under monotonic loading. Results indicate that the GGBS-dolomite GPC exhibited maximum compressive strength at a 70:30 ratio, outperforming GGBS GPC by 13%. The workability of GGBS-dolomite GPC was significantly higher than that of cement concrete, and strength properties of SFGPC surpassed those of GPC, with an increase in compressive, tensile, and flexural strength with the addition of 0.75% steel fiber. Modulus of elasticity and Poisson's ratio also increased, leading to a 2.5 times higher ductility in SFGPC 0.75 compared to geopolymer concrete. Numerical analysis aligned well with experimental results, showcasing improved load-carrying capacity in SFGPC, with a 17%, 12%, and 9% increase in ultimate load for SFGPC 0.75, 0.5, and 0.25 specimens, respectively, compared to cement concrete. Additionally, SFGPC exhibited finer cracks than ordinary Portland cement (OPC) concrete, emphasizing its potential for enhanced performance in structural application.

III. MATERIALS USED:

1. Concrete

The concrete mix proportion designed by IS method to achieve the strength of 25 N/mm2 and was 1:1.9:3.2 by weight. The designed water cement ratio was 0.42. Concrete cube specimens were cast for each batching and tested at the age of 7,14 & 28 days to determine the compressive strength of concrete. The average compressive strength of the concrete was 31.6N/mm2

2. Geo-polymer Mortar Panels

Geopolymer mortar panels refer to construction panels made using geopolymer mortar as a binding material. Geopolymers are inorganic polymers that can be used as a cementitious binder in construction materials. Geopolymer technology offers an alternative to traditional Portland cement-based materials, providing potential advantages in terms of reduced environmental impact and improved performance.It is a composition of fly ash, water, sodium hydroxide, sodium meta silicate, plasticizers and polyvinyl alcohol.

3. Cement

Cement is a crucial building material that serves as a binding agent in the construction industry.It is used to make concrete and mortar, which are integral components in a wide range of construction projects.

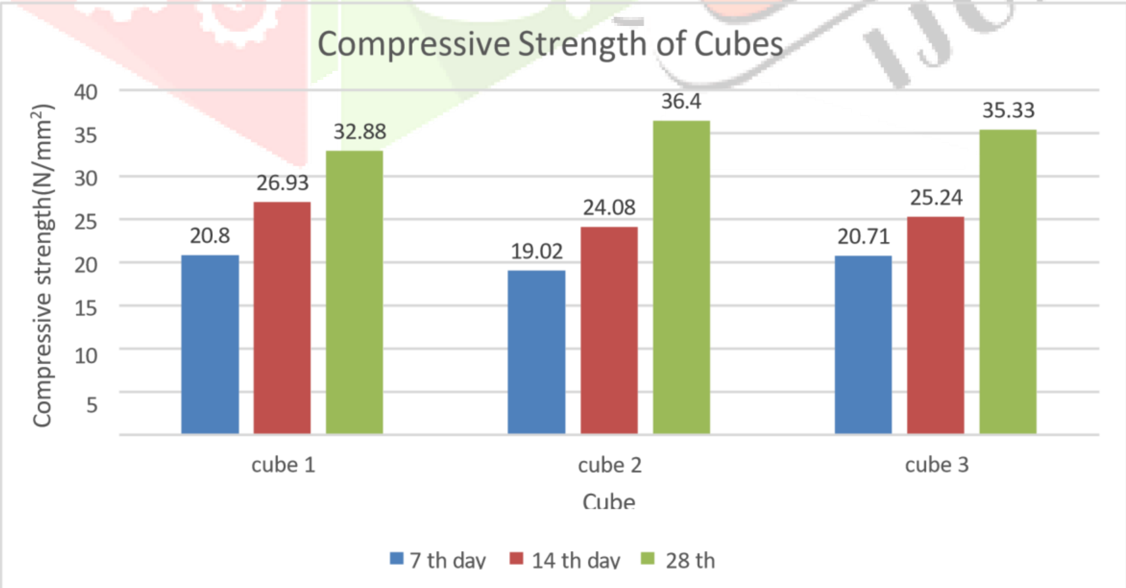
4. Reinforcement

Reinforcement is a critical element in the design and construction of durable and safe structures. Engineers carefully analyze the structural requirements and determine the appropriate type, amount, and placement of reinforcement to ensure that the finished construction meets design specifications and regulatory standards.

IV. COMPRESSIVE STRENGTH OF CUBES

Table 4.1: Comparison of compressive strength of cubes

Cubes	7th day strength	14th day strength	28th day strength
Cube 1	20.8 N/mm²	26.93 N/mm²	32.88 N/mm²
Cube 2	19.02 N/mm²	24.08 N/mm²	36.40 N/mm²
Cube 3	20.71 N/mm²	25.24 N/mm²	35.33 N/mm²



V. GEOPOLYMER MORTAR PANELS:

Geopolymer mortar panels represent a cutting-edge advancement in construction materials, presenting an alternative paradigm to traditional concrete. These panels are crafted from geopolymers, which are synthesized from aluminosilicate sources like fly ash or metakaolin. Through geopolymerization, a chemical process distinct from the use of Portland cement, these panels form a robust molecular network, imparting exceptional mechanical properties.

The standout features of geopolymer mortar panels include high compressive strength, durability, and resistance to chemical deterioration. This makes them particularly effective in bolstering the structural integrity of reinforced concrete elements, especially in terms of enhancing shear capacity.

In addition to their mechanical prowess, geopolymer mortar panels play a pivotal role in promoting sustainable construction practices. The elimination of Portland cement, a major contributor to carbon emissions in traditional concrete, positions these panels as an environmentally friendly solution. This aligns with the global trend towards reducing the ecological impact of construction materials, emphasizing the importance of environmentally sustainable alternatives.

Despite the promising attributes of geopolymer mortar panels, challenges such as standardization in production and application methods remain. Ongoing research efforts are dedicated to addressing these challenges and further refining the use of geopolymer materials in the construction industry. As the demand for sustainable building solutions continues to rise, geopolymer mortar panels stand as a noteworthy contender in the quest for more environmentally conscious and high-performance construction materials.

Fig.5.1: Geopolymer mortar panel

A. SPECIFIC GRAVITY OF CEMENT

The specific gravity of cement refers to the ratio of the density of cement to the density of a reference substance, usually water, at a specific temperature. It is a measure that helps in assessing the density or mass of cement relative to water. Specific gravity is an important property of cement and is often used in quality control and mix design in the field of construction and concrete production.

Specific gravity values can vary slightly depending on factors such as the type of cement and its composition. The specific gravity of cement is used in mix design calculations to ensure that the proportions of cement, aggregates, and water in a concrete mi x are appropriate for achieving the desired properties and strength.

VI. PRELIMINARY TESTS ON CEMENT

Required Materials & Apparatus:

1. Kerosene
2. Portland pozzolana Cement
3. Le-Chatelier Flask of 250 ml or Specific
4. Pycnometer of 100 ml
5. Weighing balance with 0.1 gm accurate

Fig 6.1.1 A Le-Chateliers apparatus

B. STANDARD CONSISTENCY OF CEMENT

The standard consistency of cement is a crucial property that helps determine the appropriate water content needed to achieve a specific viscosity or consistency of cement paste.

During the test, various proportions of water are added to a sample of cement to create a paste. The aim is to identify the water content at which the cement paste exhibits a particular level of consistency. This consistency is typically determined using a device like the Vicat apparatus, which measures the penetration or deformation of the cement paste.

The standard consistency is expressed as a percentage, representing the ratio of the weight of water to the weight of the cement in the paste. This ratio often falls within the range of 22% to 30%, though specific values may vary depending on the type of cement being tested.

The standard consistency test is a vital aspect of quality control in cement manufacturing. It ensures that cement behaves predictably in terms of workability and setting time, both of which are critical factors in construction applications. Different types of cement may exhibit slightly different standard consistencies due to variations in their composition, which can impact their performance characteristics. By establishing a standard consistency, manufacturers and construction professionals can better understand and control the properties of the cement they are working with.

Required Materials & Apparatus:

1. Vicat apparatus
2. Needles
3. Movable scale

Fig 6.1.2 B: Vicat apparatus

C. INITIAL SETTING TIME

4. Graduated scale
5. Vicat mould

The initial setting time of cement is the time elapsed between the moment water is added to the cement and the time at which the cement paste starts losing its plasticity and begins to harden. This property is crucial in construction because it determines the timeframe within which the concrete or mortar mix can be placed and finished before it becomes too rigid. In this test, a Vicat apparatus or a similar device is used to measure the penetration resistance of the cement paste. The initial setting time is the point at which the penetration resistance reaches a specified value.

The initial setting time is influenced by various factors, including the type of cement, water-cement ratio, temperature, and any chemical admixtures used in the mix. Generally, the initial setting time for ordinary Portland cement is around 30 to 45 minutes under normal conditions. Rapid-setting cements may have much shorter initial setting times, which can be advantageous in certain construction applications where quick setting and early strength development are desired.

Understanding the initial setting time of cement is crucial for construction scheduling and quality control. It helps ensure that the concrete or mortar mix remains workable during placement and finishing operations, allowing for proper construction procedures to be followed. It's important to note that the setting time of cement includes both initial setting time and final setting time, with the latter marking the point when the cement paste becomes completely rigid.

Required Materials & Apparatus:

1. Vicat apparatus
2. Balance
3. Measuring cylinder
4. Stop watch
5. Glass plate
6. Enamel tray
7. Trowel

Fig 4.2.2 C: Vicat apparatus

D. FINAL SETTING TIME

The final setting time of cement is the time elapsed between the moment water is added to the cement and the time at which the cement paste has completely lost its plasticity and has attained sufficient rigidity to resist a specified amount of pressure without any perceptible indentation. In other words, it is the duration required for the cement to transition from a plastic state to a hardened state.

The final setting time is a critical parameter in construction as it determines when the cement paste or concrete mix has achieved its ultimate hardness and is ready for further construction activities. This includes activities such as form removal, finishing, and loading.

Similar to the initial setting time, the final setting time is influenced by factors like the type of cement, water-cement ratio, temperature, and any admixtures used. Standard test methods, such as the Vicat apparatus test, are employed to determine the final setting time. In this test, a needle or plunger is used to penetrate the cement paste at regular intervals after mixing, and the final setting time is the point at which the penetration is resisted to a greater extent compared to the initial setting time.

It's important for construction projects to adhere to the specified final setting time to ensure that the concrete has reached an appropriate level of hardness for structural integrity and durability. The final setting time is often regulated by construction codes and standards to ensure the proper performance of the cement in various applications.

E. FINENESS OF CEMENT

The fineness of cement is a measure of the size of particles of cement and is expressed in terms of the specific surface area of cement. The fineness of cement is measured as the % weight retained on a 90μm IS sieve over the total weight of the sample.

Required Materials and Apparatus:

1. 1.90-micron sieve
2. Sieve shaker
3. Weighing balance
4. Sieve with pan

F. WORKABLITY OF CONCRETE

The term "workability" in the context of concrete refers to the ease with which a freshly mixed concrete or mortar can be mixed, placed, compacted, and finished during construction. Workability is a crucial property as it directly influences the ease of handling and the quality of the finished product. It is primarily influenced by the consistency and fluidity of the concrete mix.

Several factors contribute to the workability of concrete, and these include:

1. Water Content: The amount of water in the mix significantly affects workability. An optimal water-cement ratio is essential to achieve the desired workability without compromising the strength and durability of the concrete.
2. Cement Fineness: Finer cement particles generally contribute to better workability by enhancing the paste's ability to coat and lubricate the aggregates.

3. Aggregates: Graded aggregates with a well-balanced particle size distribution can improve workability. Smooth and rounded aggregates also tend to enhance the workability of concrete.
4. Admixtures: Certain chemical admixtures, such as water-reducing agents or plasticizers, can be added to the mix to enhance workability without increasing the water content excessively.
5. Mixing Time and Method: Proper mixing of concrete is essential to achieve uniform distribution of materials. Overmixing or undermixing can affect workability.
6. Temperature: Concrete temperature can influence workability. High temperatures can accelerate setting, reducing workability, while low temperatures can slow down setting.

The assessment of workability is subjective and can vary based on the construction application. Methods for measuring workability include the slump test, which measures the consistency of concrete, and the flow table test, which assesses the flow characteristics of self-compacting concrete. The desired level of workability depends on factors such as the construction method, transportation, and placement requirements of the concrete. Balancing workability with other performance factors, such as strength and durability, is essential in achieving a concrete mix that meets the specific needs of a construction project.

VII. CONCLUSION

In summary, the collective findings from the reviewed studies underscore the multifaceted and promising nature of shear strengthening techniques for reinforced concrete beams, particularly emphasizing the role of geopolymer materials in this context. The meticulous experimental and analytical investigations presented in the literature shed light on the efficacy of geopolymer-mortar panels (GMPs) as a viable solution for enhancing shear capacity in reinforced-concrete (RC) beams. The studies explore various parameters, such as anchor-bolt spacing, wire mesh presence, and binding material types, revealing substantial improvements ranging from 14.1% to 34.9% in shear capacity for GMP-strengthened beams compared to their unstrengthened counterparts. The shift from brittle to ductile failure, especially with optimal anchor bolt spacing and wire mesh, underscores the potential of GMP in transforming the failure modes of RC beams. The alignment between experimental results and analytical models based on the simplified-modified-compression-field theory further supports the effectiveness of GMP. Moreover, comparisons with alternative strengthening methods, such as Portland-cement-mortar panels, emphasize the unique advantages of GMP, showcasing its flexibility and potential contributions to advancements in structural engineering practices. While geopolymer materials hold promise, the broader literature also delves into other innovative approaches like geopolymer concrete, textile- reinforced mortar (TRM), textile-reinforced geopolymer mortar (TRGM), and small-diameter CFRP bar-reinforced geopolymer matrix (FRGM). These studies collectively contribute to a nuanced understanding of the diverse materials and methodologies available for achieving optimal shear strengthening outcomes. The environmental considerations associated with geopolymer materials, such as reduced carbon emissions and utilization of industrial by-products, align with the industry's growing focus on sustainability. However, it is crucial to acknowledge persistent challenges, including standardization issues, material availability, and cost considerations, necessitating ongoing research endeavors to refine and enhance the practical application of geopolymer- based solutions in realworld construction scenarios. Thus, the reviewed literature not only highlights the advancements in shear strengthening techniques but also underscores the ongoing efforts required to fully unlock the potential of geopolymer materials and other innovative approaches in bolstering the resilience and sustainability of reinforced concrete structures.

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