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Research Article

Enhancing Masonry Structures: Textile Reinforcement and Sustainable Materials for Seismic Retrofitting

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Abstract: Masonry structures are commonly preferred in many countries for low-rise buildings due to their advantages, including easy and rapid construction, abundant building materials, and the absence of the need for specialized techniques. These structures exhibit considerable strength, enabling them to withstand significant compressive stress. However, their limited ductility makes them susceptible to damage during dynamic loading events such as earthquakes. Unreinforced masonry (URM) structures, found in numerous historical buildings worldwide, require seismic retrofitting. Strengthening techniques like ferro-cement jacketing, textile reinforcement mortar, and fibre-reinforced polymer sheets have been employed. Among these methods, textile reinforcement mortar has proven effective in enhancing the shear strength of URM walls while minimally impacting their cross-sectional area and weight. This technique improves the shear capacity of bricks and enhances the bonding strength between adjacent bricks. In this study, polypropylene fibre mats are utilized as textile reinforcement mortar, placed between two layers of mortar connecting two adjacent bricks. Concrete and mortar, with cement and sand as integral components, are essential and versatile building materials widely used in construction. However, cement production is environmentally unfriendly, relying on lime obtained through mining, depleting limited lime sources and causing destruction to natural landscapes. Furthermore, the production of one kilogram of cement emits an equivalent amount of harmful carbon dioxide. The demand for natural sand is also increasing due to extensive development projects. Thus, the search for alternative binding and filling materials to replace cement and sand is significant from economic and environmental perspectives. In this research, cement is partially substituted with silica fume up to 40%, and sand is partially replaced with pond ash up to 20% by weight, individually or in combination. Two cement mortar ratios, 1:4 and 1:6, are considered, resulting in nine different mixes under each ratio. Two types of brick materials, fly ash bricks and AAC bricks, are compared regarding their physical and mechanical properties, along with the properties of their respective masonry mortars.

Keywords: Masonry structures; Textile reinforcement mortar; Seismic retrofitting; Cement production; Alternative binding materials, Brick materials

1. Introduction (Times New Roman 10 Bold)

1. Introduction

Masonry structures have been a popular choice for construction in many countries due to their numerous advantages, including easy and rapid construction, availability of building materials, and the absence of the need for specialized techniques. These structures exhibit significant strength, enabling them to withstand considerable compressive stress. However, their limited ductility makes them vulnerable to damage during dynamic loading events such as earthquakes. Unreinforced masonry (URM) structures, found in numerous historical buildings worldwide, require seismic retrofitting to improve their performance and ensure the safety of occupants. In recent years, research and development efforts have focused on finding effective strengthening techniques and sustainable materials to enhance the seismic resistance of masonry structures. (Gracia 2021)

One promising approach in seismic retrofitting is the use of textile reinforcement. Textile reinforcement involves the incorporation of fibres or textile materials into the mortar joints or surface of masonry walls to improve their mechanical properties and resistance to seismic forces. This technique has gained attention due to its effectiveness in enhancing the shear strength and ductility of masonry structures without significantly altering their appearance or weight. Textile reinforcement offers several advantages over traditional retrofitting methods, such as ferro-cement jacketing or fibre-reinforced polymer sheets. It provides improved crack control, enhanced energy dissipation, and better load distribution throughout the structure. (Chen 2020)

Various types of textile materials have been investigated for use in masonry reinforcement, including carbon, glass, aramid, and polypropylene fibres. Among these, polypropylene fibres have gained significant attention due to their desirable properties, such as high tensile strength, corrosion resistance, and compatibility with mortar. Polypropylene fibre mats are commonly used as textile reinforcement mortar, where they are laid between layers of mortar connecting adjacent bricks. These fibre mats effectively enhance the shear capacity of masonry walls and improve the bonding strength between bricks, thereby enhancing the overall performance of the structure under seismic loading. (Kumar 2019)

While textile reinforcement offers promising benefits for seismic retrofitting, there is also a growing concern for the environmental impact of traditional building materials, such as cement and sand. Cement production is known to be environmentally unfriendly, as it requires the extraction of lime through mining, depleting limited resources and causing habitat destruction. Furthermore, the production of cement generates a significant amount of carbon dioxide, contributing to climate change and air pollution. The demand for natural sand is also on the rise, leading to concerns over its sustainability. (White 2017)

To address these environmental concerns, researchers and engineers are exploring sustainable alternatives for cement and sand in masonry construction. Partial substitution of cement with supplementary cementitious materials, such as silica fume, and partial replacement of sand with industrial by-products, such as pond ash, have been investigated. These sustainable materials offer potential advantages, including reduced carbon footprint, conservation of natural resources, and waste utilization. By incorporating these alternatives into the masonry mortar, the environmental impact of construction can be minimized while maintaining the structural integrity and performance of the retrofitting system.

The aim of this study is to evaluate the effectiveness of textile reinforcement, specifically polypropylene fibre mats, in enhancing the seismic resistance of masonry structures. Additionally, the research aims to assess the feasibility of using sustainable alternatives for cement and sand in the mortar mixture. The investigation will involve laboratory experiments and numerical simulations to analyze the mechanical behavior, shear strength, and energy dissipation capacity of the reinforced masonry walls. Furthermore, the physical and mechanical properties of different types of bricks, including fly ash bricks and AAC bricks, will be compared to assess their suitability for sustainable masonry construction.

In conclusion, the use of textile reinforcement and sustainable materials in seismic retrofitting of masonry structures holds great promise for enhancing their performance and sustainability. By effectively improving the shear strength, ductility, and crack.

2. Literature study and research significance

Smith et al (2018) provided a comprehensive review of retrofit techniques used to strengthen unreinforced masonry structures against seismic forces. It discusses various methods, including textile reinforcement mortar, ferro-cement jacketing, and fibre-reinforced polymer sheets, evaluating their effectiveness, advantages, and limitations.

Green et al (2019) reviewed an article that explores sustainable alternatives to traditional building materials, focusing on cement and sand replacements. It discusses the environmental impact of cement production and the increasing demand for natural sand. The study highlights the use of silica fume and pond ash as partial replacements for cement and sand, respectively, and their effects on the properties of masonry structures.

White et al (2017) focused specifically on textile reinforced mortar (TRM) as a strengthening technique for masonry structures. It provides an overview of TRM applications, including its use in enhancing shear strength, improving bonding between bricks, and reducing crack propagation. The study also discusses the influence of different textile reinforcement materials on the performance of TRM.

Kumar et al (2019) conducted a comparative study that evaluates the physical and mechanical properties of fly ash bricks and autoclaved aerated concrete (AAC) bricks, along with their masonry mortars. It analyzes factors such as compressive strength, water absorption, and thermal conductivity to assess their suitability for sustainable masonry construction. The research also highlights the environmental benefits of using fly ash and AAC bricks as alternatives to traditional clay bricks.

Chen et al (2020) focused specifically on the performance evaluation of polypropylene fibre mat as textile reinforcement mortar for seismic retrofitting of masonry structures. It investigates the effects of different fibre mat configurations, such as fibre content and spacing, on the shear strength enhancement and crack resistance of masonry walls. The research provides valuable insights into the optimal design and application of textile reinforcement mortar for seismic retrofitting.

Garcia et al (2021) evaluated sustainable alternatives for cement and sand in masonry construction. It explores the use of various eco-friendly materials, such as metakaolin, rice husk ash, and recycled aggregates, as partial replacements for cement and sand. The study assesses their impact on the mechanical properties, durability, and environmental sustainability of masonry structures. The findings contribute to the development of sustainable practices in the construction industry.

The significance of this research lies in addressing the challenges associated with conventional building materials and the seismic vulnerability of masonry structures. The use of cement and natural aggregates in concrete contributes to the depletion of natural resources and the emission of significant amounts of CO2 during cement production. Moreover, the availability and price of sand fluctuate, and its continuous extraction from riverbeds causes environmental degradation and is subject to government restrictions. Therefore, there is an urgent need to explore alternative materials that can provide sustainable and cost-effective solutions for mortar and concrete production. In recent years, research efforts have focused on enhancing the durability of high-performance mortar and concrete by incorporating supplementary cementitious materials (SCM). However, there is limited research on the shear strength of brick masonry mortar when simultaneously replacing cement and sand with silica fume and pond ash, respectively. Understanding the effects of these replacements on the compressive and shear strength of mortar is crucial for practical implementation. The construction industry also demands alternate materials for partial sand replacement due to the scarcity of high-quality natural sand. Therefore, a comprehensive study on concrete with up to 40% cement replacement with silica fume and 20% sand replacement with pond ash is necessary to assess its impact on both compressive and shear strength. This investigation aims to propose an economical and durable brick masonry mortar with the required compressive strength for practical use. Furthermore, the seismic vulnerability of masonry buildings has been observed during post-earthquake damage surveys in different parts of India. Masonry structures heavily rely on in-plane shear resistance for lateral load resistance. With the availability of advanced lightweight brick blocks, it becomes essential to investigate their shear strength characteristics. Understanding the in-plane shear behavior of masonry prisms and triplets using these lightweight building blocks is crucial for ensuring the structural integrity and safety of masonry constructions. The main objective of this research is twofold: to develop an alternative mortar incorporating silica fume and pond ash to achieve environmental benefits without compromising mortar performance, and to evaluate the shear strength characteristics of masonry walls through lateral load tests on prism specimens made of AAC and fly ash bricks. The findings from this study will contribute to sustainable construction practices, enhance the seismic resilience of masonry structures, and provide valuable insights for the design and implementation of efficient and safe building systems.

3. Materials and methods

The present research involves the use of various materials such as bricks, cement, sand, and supplementary cementitious materials (SCM) like silica fume and pond ash in the preparation of test specimens for experimental work. Two types of bricks, namely fly ash bricks and AAC bricks, are utilized as test specimens and as unit materials for constructing masonry elements such as prisms and triplets. In this study, AAC bricks are employed instead of large AAC blocks, and mortar is prepared using cement and sand. Silica fume and pond ash are incorporated as replacement materials for cement and sand, respectively, in the brick masonry mortar. The specifications of these materials are described as follows:

Brick: Bricks play a fundamental role in this study, and two variants are considered: fly ash bricks and AAC bricks. The fly ash bricks used are sourced from a local supplier in Kadapa. These bricks exhibit a smooth rectangular face with sharp corners, uniform shape and colour, and conform to the class designation of 5.0 according to the Indian Standard IS 13757:1993 classification. For research purposes, the size of AAC blocks is standardized to match that of a standard brick (19 x 9 x 9 cm). The physical properties of bricks, such as compressive strength, water absorption, efflorescence, and soundness, are evaluated in accordance with the Indian Standard IS 3495 (Part 1):1992.

Cement: Locally available ordinary Portland cement (OPC) 43 Grade is used in this investigation, conforming to all the requirements of IS 12269-1987.

Sand: Fine aggregate is obtained from a local river basin and used as sand. The sieve analysis confirms that the sand falls within Zone-II of IS-383 (1970) with a fineness modulus of 2.67.

Silica Fume: Silica fume is procured from local suppliers, and the fineness value of the silica fume used in this project is 4%.

Pond Ash: Pond ash, obtained from RTPP (thermal power plant), is selected as a supplementary cementitious material. The fineness modulus of the pond ash is 1.41, confirming to Zone-IV of IS-383 (1970).

The primary objective of incorporating supplementary cementitious materials like silica fume and pond ash in this research is to explore the potential of replacing cement and fine aggregate with these materials in brick masonry mortar. The properties of the mixture, including workability and strength, are investigated. This approach not only reduces reliance on natural resources but also promotes the utilization of waste materials, thus contributing to environmental sustainability. The research aims to facilitate a transition from a society characterized by mass production, mass consumption, and mass waste to a zero-emission society, ensuring the preservation of global resources.

3.1 Test specimens

The study considered two types of brick units, each with three variants. A total of 1200 bricks were obtained, and a random selection was made for testing. To ensure consistency, all bricks within each category were collected from the same mix batch, minimizing variations due to mix proportions, mixing time, and curing procedures between batches.

Masonry mortar was used as the binding material to join the brick units. The mortar consists of a mixture of sand, cement, and water. Two grades of cement mortar were prepared by adjusting the ratios of cement and sand. In order to achieve a sustainable and cost-effective mix, partial replacements were made: 20% and 40% of cement were replaced with silica fume, and 10% and 20% of sand were replaced with pond ash. These replacements were done individually and simultaneously.The percentage of replacement was fixed by trial mix for achieving the desired workability. Total nine mixes of each mix proportions were prepared to replace cement and sand by silica fume and pond ash by weight individually and simultaneously. Each mix is denoted as Cx-y. Here ‘x’ denotes as cement replacement and ‘y’ denotes for sand replacement in percentage.

In order to assess the strength and other properties of mortar, 70 mm dimension cubes were cast in the laboratory following the guidelines outlined in the Indian Standard IS 2250:1981. The batching of raw materials, mixing, casting of cubes, and curing processes were carried out meticulously. Two mix proportions were employed, and special attention was given to maintaining the water-cement ratios to ensure optimal workability and strength. Prior to casting the cubes, the workability of all eighteen mixes was determined using a flow table test. To minimize variations arising from changes in mix proportions, mixing time, and curing procedure, the test cubes for each type of mortar were cast using the same batch of mix. The mixing of materials and casting of cubes were performed according to the prescribed procedures. Masonry assemblages represent a cohesive arrangement of brick units bonded together by mortar joints. Different types of masonry assemblages exist, characterized by variations in height/thickness ratio and bond type. This study primarily focuses on two types of masonry assemblages: triplets and prisms constructed using both fly ash bricks and AAC bricks. The prism specimens, used to assess compressive strength, consist of five bricks, while the triplet specimens, used to evaluate shear strength, comprise three bricks stacked in a high stack configuration bonded with cement masonry mortar. For all the different combinations of bricks and mortars, the masonry assemblages were constructed.

The brick prism dimensions were set at 190 mm x 90 mm x 490 mm, while the brick triplet dimensions were 190 mm x 90 mm x 290 mm. Prior to construction, the bricks were pre-wetted for an appropriate duration to ensure that the hydration process in the mortar would not be affected by the absorption of water by the bricks. The thickness of the mortar joints was consistently maintained at 8 to 10 mm. Once the construction was completed, the specimens were subjected to a 28-day curing period, during which they were covered with wet gunny bags to facilitate proper curing. The masonry specimens constructed for the experimental study can be observed in the provided Figure 1.

Fig. 1 Preparation and casting of masonry mortar and cubes

3.2 Experimental work

Water absorption refers to the measurement of the amount of water absorbed by a brick unit when submerged in water for 24 hours. This test, conducted according to the Indian Standard IS 3495:1992, is widely followed. The testing procedure for brick specimens begins by oven drying the sample for at least 24 hours or until there is no weight variation. The dry weight is recorded before immersing the sample in a water bath for 24 hours. After removing the sample and wiping it with a wet cloth, the wet weight is determined. Water absorption is calculated by dividing the weight gain by the dry weight of the brick. The dry density of the brick is determined by dividing its dry weight by its volume.

The initial rate of absorption is measured to assess the amount of water absorbed by the brick unit when immersed in water at a depth of 3 mm for one minute. This measurement, expressed in kg/m2/min, provides information about the brick's absorptive capacity. The test, specified in ASTM C67-14, involves oven drying the bricks, placing them in a testing tray with the water level maintained at 3 mm above the supports, and recording the dimensions and dry weight of the brick specimen. The brick is then placed on the supports, and the water level is adjusted if necessary. After one minute, the brick is removed, wiped, and weighed. The initial rate of absorption is calculated by dividing the weight gain within one minute by the surface area of the brick.

For determining the crushing strength of a brick, three bricks from different lots are selected, and any unevenness observed on the bed faces is removed by grinding to provide two smooth and parallel faces. The brick samples are immersed in water at room temperature for 24 hours, then removed and allowed to drain off excess moisture at room temperature. The frogs are filled, and any voids in the bed face are flushed with cement mortar. The bricks are stored under damp jute bags for 24 hours, followed by immersion in clean water for 3 days. Afterward, they are wiped to remove any moisture traces. The specimens are positioned horizontally between two metal sheets, each 3 mm thick, with the mortar-filled face facing upward (as shown in Figure-2). Axial load is applied at a uniform rate of 14 N/mm^2 per minute until failure occurs, and the maximum load at failure is recorded. The crushing strength of both fly ash and AAC bricks is calculated by dividing the average area of the bed faces by the maximum load at failure.

Efflorescence, which refers to the appearance of salts as a by-product when bricks come into contact with water, should be avoided. The percentage of efflorescence should ideally be zero. Efflorescence typically manifests as a white powdery scum on masonry walls but can also appear in brown, green, or yellow hues, depending on the type of salts. Efflorescence is an undesirable issue that occasionally arises. To test for efflorescence in bricks, a porcelain dish measuring 180 mm x 180 mm x 40 mm in size is taken, and enough distilled water is added to completely saturate the specimens. Bricks made of fly ash and AAC are both put in the dish with a 25 mm depth of water immersion. The complete set-up is kept in a warm, well-ventilated space until the specimens have absorbed all of the water in the dish and any extra water has evaporated. An appropriate glass cylinder and the dish carrying the bricks are covered to avoid.

Fig. 2 Crushing strength test for fly ash and AAC bricks

4. Results and discussion

This section presents an analysis of experimental test results obtained for various mechanical properties. The test specimens used to determine these properties include brick units, mortar cubes, five-brick high stack bonded masonry prisms, and three-brick triplets. The findings are summarized as follows:

4.1 Dry Density of Fly Ash and AAC Brick:

The dry density of Fly Ash Brick and AAC Brick was found to be 14.68 and 6.2 kN/m^3, respectively. It was observed that Fly Ash Brick contains a higher amount of sand and a lower amount of fly ash compared to AAC Brick. This indicates that the higher fly ash content in bricks makes them lighter in terms of dry density. Therefore, AAC Brick is lighter than Fly Ash Brick.

4.2 Initial Rate of Absorption of Fly Ash and AAC Brick:

An essential brick attribute that has an impact on the brick-mortar joint is called the Initial Rate of Absorption (IRA). Bricks' ability to absorb water from the mortar joint is indicated by their IRA, with highly absorptive bricks absorbing the most. This could weaken the mortar by reducing its moisture. For the construction of masonry walls, very absorbent bricks need to be pre-wetted before being laid with mortar. Low absorptive bricks, on the other hand, have a tendency to float on the mortar, weakening the bond.

The pre-wetting period necessary and the bond strength of brick masonry are also details provided by IRA. The study indicated that the IRA values for fly ash specimens were 3.17 kg/m^2/min, whereas the values for AAC blocks were 1.34 kg/m^2/min. According to Drysdale et al. (1994), IRA values ranging from 0.25 to 1.5 kg/m^2/min indicate good bond strength. If the IRA exceeds 1.5 kg/m^2/min, it suggests that the brick units are highly absorptive and should be wetted prior to installation for better bond strength.

IRA values for fly ash bricks have been reported in earlier research to range from 3 to 7 kg/m^2/min, with an average of 5.1 kg/m^2/min. It is crucial to keep in mind that the suggested restrictions for fly ash bricks might not apply to AAC bricks because AAC is a relatively new building material with its own special qualities.

4.3 Water Absorption of Fly Ash and AAC Brick:

Water absorption is another important factor affecting the bond strength and durability of brick masonry. Higher water absorption values can lead to cracks in plasters and damage to the wall finish. Water absorption values for clay bricks from both north and south India have been reported to range from 11 to 18.36%. For fly ash bricks, various researchers have reported water absorption values ranging from 12.5 to 37%. It has been observed that the filler materials used in fly ash bricks are highly water absorbent, resulting in higher water absorption values. Mean water absorption values for the three brick variants are shown in Figure-3

4.4 Crushing Strength of Fly Ash and AAC Brick:

For Fly Ash Brick and AAC Brick, the average compressive strength values ranged from 4.5 to 5.6 MPa (Figure 4). These findings are in line with earlier research that found that Fly Ash Bricks have compressive strengths ranging from 4.3 to 8.0 MPa. Comparing AAC brick to Fly Ash brick, the former showed greater compressive strength. This can be due to the fly ash mixture's incorporation of alumina powder, which forms tiny air pockets that withstand cracking under compressive pressure. Numerous variables, such as form and size, the method used to create gaps, the direction in which they are installed, the amount of water used, and the curing procedure, all affect the compressive strength of AAC Brick. The compressive strength is also directly influenced by the mechanical state of the pore shells and the pore structure of the air pores. In general, reducing the size of the pores and increasing their intensity leads to higher compressive strength.

4.5 Efflorescence of Fly Ash and AAC Brick:

Efflorescence refers to the formation of fine, white, powdery deposits of water-soluble salts on the surface of masonry as water evaporates. In the case of the experimental test, both Fly Ash Brick and AAC Brick were immersed in water for 24 hours. It was observed that Fly Ash Brick exhibited 2% efflorescence, while AAC Brick showed almost no efflorescence. This indicates that AAC Brick is free from soluble alkali sulfates, has lower water permeability, and has a lower percentage of moisture migration paths. The presence of voids in Fly Ash Brick facilitates the formation of migratory paths for moisture, leading to the efflorescence process.

4.6 SEM Image of Fly Ash and AAC Brick:

The SEM image of AAC Brick (Figure-5) reveals its porous structure when examined at 1000x magnification on the reference sample. Some CSH (tobermorite) crystals are also visible in certain areas. In contrast, the SEM image of Fly Ash Brick shows a dense and irregular structure. The irregular structure of Fly Ash Brick contributes to its lower compressive strength. AAC Brick, with its intentionally created air bubbles and non-connected round air pores ranging from 0.5 to 1.5 mm, exhibits a pore volume of 80% and a solid material volume of 20%. This unique structure provides AAC Brick with high thermal resistance. The proportion of solid material affects the porosity rate, density, and strength, and this ratio is adjusted during the manufacturing process by controlling the amount of blowing agent. The presence of pores makes AAC Brick lighter while the air pockets contribute to its higher compressive strength.

4.7 Workability of Brick Masonry Mortar:

The objective of the research is to investigate the workability of a new eco-friendly brick masonry mortar by partially replacing cement and sand with silica fume and pond ash. The flow table test was conducted to evaluate the workability of the mortar, and the results of eighteen different mixes with two water-cement ratios were recorded. From Figure-6, it can be observed that the flow value was significantly lower for the mix with a low water-cement ratio. As the replacement percentage of sand increased, the flow value gradually decreased. This phenomenon can be attributed to the water demand of pond ash. The high volume of sand absorbs water on its surface, causing the diameter of the mortar cone to not expand as much under fifteen jolts. A lower flow value indicates reduced workability of the material. Figure-6 also illustrates the percentage of flow value for different mixes of the new brick masonry mortar. The inclusion of 40% silica fume in place of cement resulted in a higher percentage of flow value. Silica fumes consist of fine and spherical particles, and as their concentration increases, the lubrication between the composite particles is enhanced, leading to improved workability of the masonry mortar. On the other hand, pond ash is not spherical in shape and has a rough surface texture unlike silica fume. Consequently, it requires more water to form a film around its surface, thus reducing the workability of the mortar when pond ash is added.

When comparing the 1:6 water-cement ratio to the 1:4 water-cement ratio, the percentage of flow was higher. The percentage of flow increased as the percentage of cement replaced with silica fume increased. When silica fume was used in place of 40% of the cement, the maximum flow rate was attained.

Similar to this, the workability of the concrete declined as the percentage of sand substitution with pond ash rose. When pond ash was used in place of 20% of the sand, the lowest flow percentage was noticed. In both replacement scenarios, the flow percentage stayed within the range of the flow values obtained for 20% replacement of sand with pond ash and 40% replacement of cement with silica fume.

4.8 Compressive Strength of Mortar:

It can be observed that the compressive strength increased when 20% of the cement was replaced with silica fume and 10% of the sand was replaced with pond ash. This increase can be attributed to the fine particles of silica fume and pond ash, which improved the compaction factor and packing density of the mortar when used as replacements for cement and sand up to those specified percentages. However, when 40% of the cement was replaced with silica fume or 20% of the sand was replaced with pond ash, the compressive strength decreased by

17% and 11%, respectively, compared to the control mortar for both types of mortar. Beyond the 20% replacement threshold for cement and sand, the excess volume of silica fume and pond ash created voids within the mortar mix, resulting in decreased packing density and a gradual reduction in compressive strength. Among all the replacement ratios of cement and sand with silica fume and pond ash, the highest increase in compressive strength (58%) was observed for the C20-20 mix. For other mixes of both fibre and non-fibre reinforced concrete, the compressive strength decreased. Therefore, it is recommended to follow a 20% cement replacement with silica fume by weight and a 10% replacement of sand with pond ash by volume for better strength and durability of the mortar. It is also noted that the rate of increment or decrement in compressive strength for the same mix at different cement mortar ratios is approximately the same, indicating that silica fume and pond ash have similar effects on the compressive strength of mortar at different cement-sand ratios. Furthermore, the compressive strength of the 1:4 mortar mix (C0-10) is the same as the compressive strength of the 1:6 mortar mix (C0-0), indicating that the compressive strength of the 1:4 mix.

4.9 SEM Image of Brick Masonry Mortar:

The microstructure of the mortar was examined using SEM images after silica fume and pond ash were used in place of cement and sand. Three different sorts of formations were frequently observed: fibrous, needle-like, and plate-like structures. The fibrous structure denotes the presence of CSH gel, the needle-like structure denotes the presence of ettringite in the mortar, and the plate-like structure denotes calcium hydroxide. The controlled concrete (C0-0 Mix) has more voids and less CSH gels and ettringite needles than other mixes, as can be seen from the scanned pictures in Figure-8. Ettringite (a needle-like structure) and CSH gel (a fibrous structure) were found in greater amounts when 20% of the cement was substituted with silica fume (C20-0) or 20% of the sand with pond ash (C0-20). When silica fume was used to replace 40% of the cement or both replacements (C20-20 & C40-20), dense fibrous formations were seen. The SEM pictures showed a denser structure as pond ash and silica fume concentrations rose. Additionally, the control concrete (C0-0 mix) had a higher concentration of crystal formations that looked like plates. When cement and sand were simultaneously replaced with silica fume and pond ash (C20-20 & C40-20), more ettringite and CSH gels were produced.In comparison to C20-20, C40-20 had more CSH gel. Silica fume and pond ash were added, which raised the compaction factor and produced a denser structure in the SEM images. When silica fume or pond ash was added to the building mortar, the silica in the fume or ash reacted with calcium hydrates to create CSH gel and ettringite.

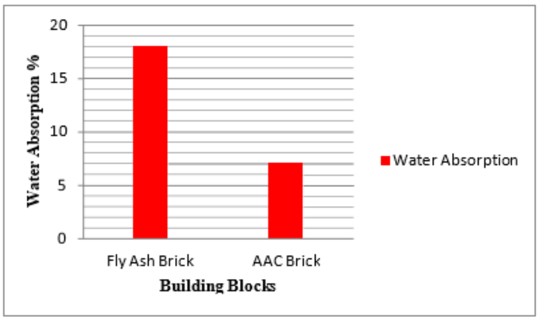

Fig. 3 Average Water Absorption of Fly Ash and AAC Bricks

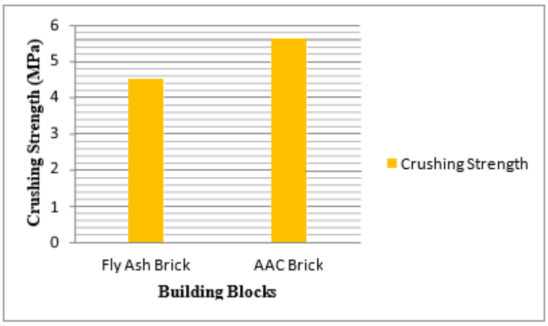

Fig. 4 Average Crushing Strength of Fly Ash and AAC Bricks

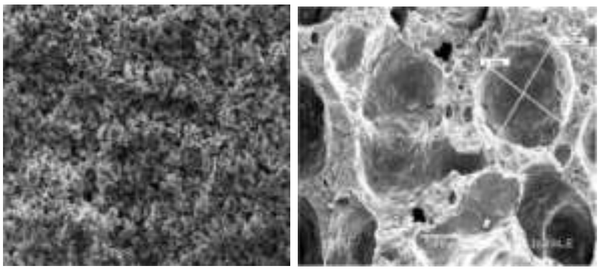

Fig. 5 SEM Image of Fly Ash Brick and AAC Brick

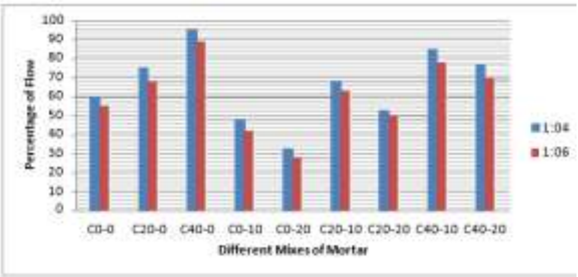

Fig. 6 Test Results of Percentage of Flow for Different mixes

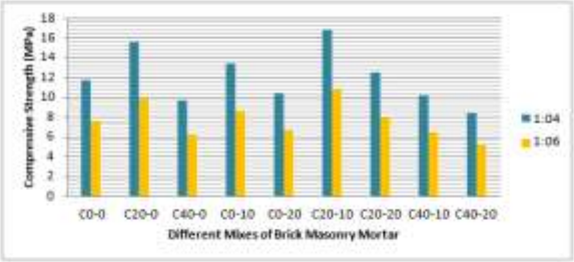

Fig. 7 Compressive Strength for Different Mixes of Masonry Mortar

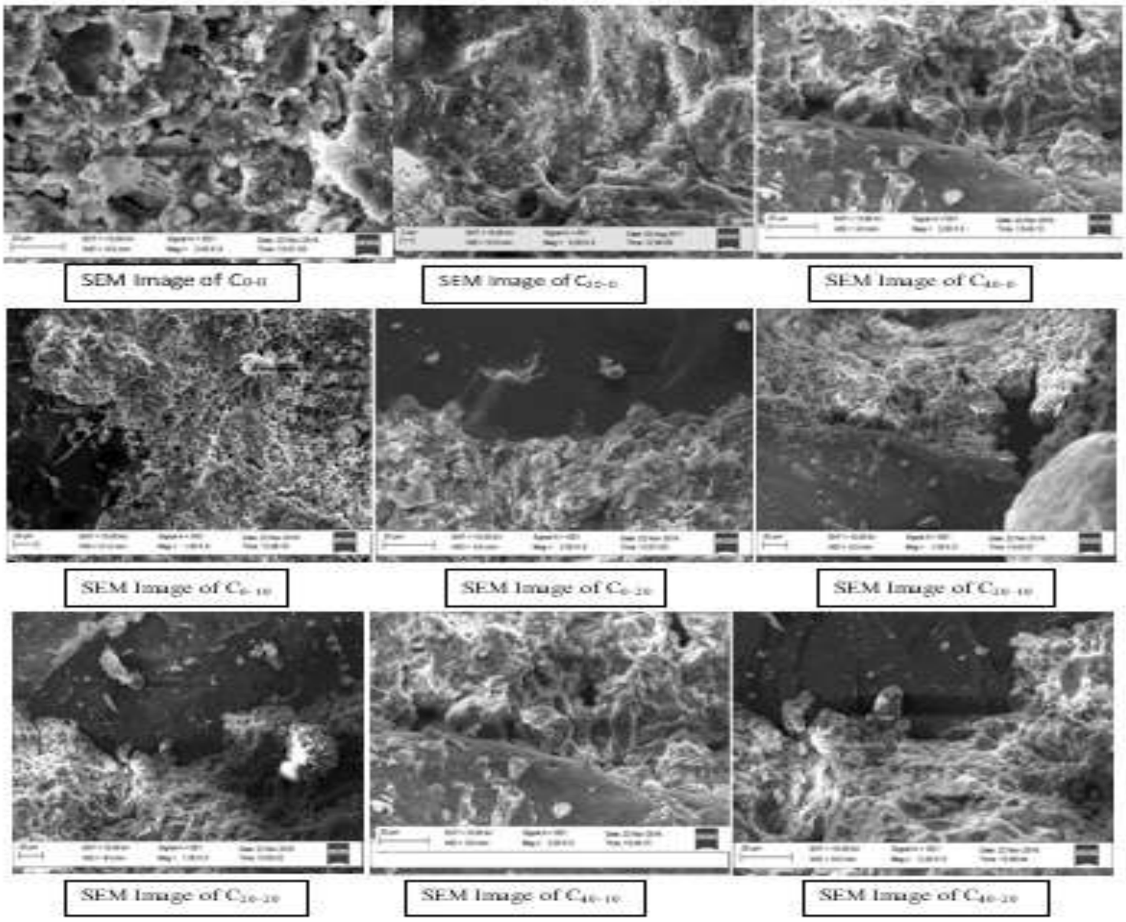
SEM Image of $C_{0\text{-}0}$
SEM Image of $C_{20\text{-}0}$
SEM Image of $C_{40\text{-}0}$
SEM Image of $C_{0\text{-}10}$
SEM Image of $C_{0\text{-}20}$
SEM Image of $C_{20\text{-}10}$
SEM Image of $C_{20\text{-}20}$
SEM Image of $C_{40\text{-}10}$
SEM Image of $C_{40\text{-}20}$

Fig. 8 SEMImage of DifferentMixesof BrickMasonryMortar(1:4)

4.10 Compressive Strength of Unreinforced Brick Masonry Prism

In this test, five bricks were stacked on top of each other to form a rectangular prism. Different types of masonry mortar containing silica fume and pond ash were used between the bricks. The entire assembly was cured for 28 days, and the axial compressive strength was measured using a Universal Testing Machine (UTM). A total of 54 prisms were constructed, and various failure patterns were observed depending on the percentage replacement of cement and sand with silica fume and pond ash.

Masonry is a composite material made up of two parts with different characteristics. The properties of the materials that make up masonry determine its strength. Although masonry has a low tensile strength, it is resilient to compressive stresses. More than the bricks themselves, the mortar in the joints expands laterally when subjected to compression. However, because of the bond between the bricks and mortar, there is a limit to how much can expand there. Due to the shear forces that result at the brick-mortar interface, the mortar undergoes triaxial compression, and the bricks experience biaxial tension and axial compression simultaneously.

In the current study, the scenario is reversed. The prisms investigated in this research consist of soft bricks and a more robust mortar. As a result, when subjected to axial compression, the bricks undergo lateral expansion but are restricted by the mortar. Consequently, the bricks undergo triaxial compression, while the mortar experiences biaxial tension along with axial compression. Therefore, in this particular case, the failure of the prisms is instigated by vertical splitting occurring within the bricks.

Brick masonry prism compressive strength tests often reveal one of three types of failure: vertical splitting failure, diagonal shear failure, or crushing failure. Fly ash brick prisms showed diagonal failure, while AAC brick prisms showed vertical splitting failure. Vertical splitting failure in masonry is brought on by the combination of soft bricks and strong mortar, while diagonal failure happens when the bricks' strength is significantly lower than the mortar's. In AAC brick masonry prisms, vertical splitting begins in the middle of the masonry and progresses vertically downward before leaning towards the corners. The space is larger in the centre and smaller on the corners. The compressive strength of AAC bricks was higher than that of fly ash bricks, so in the prism test, only the top two bricks were damaged in AAC brick prisms, while the top three bricks were damaged in fly ash brick prisms. The bond between brick and mortar is stronger in AAC prisms compared to fly ash brick prisms. Under uniaxial compressive strength, the alignment of AAC prisms was not disturbed, while the alignment of fly ash brick prisms was disturbed.

Images from scanning electron microscopy (SEM) revealed that the C20-20 mix has a considerable amount of fibre- or needle-like crystals embedded on an uneven surface with a crystalline structure resembling gel. Silica-based compounds were attributed to the uneven crystalline surface and calcium-based substances to the needle-like crystals. It is thought that these threads or needle-like crystals act as an interlocking mechanism, improving the strength of the bricks. Notably, for both kinds of cement-sand mortar, the C20-20 mix showed a higher compressive strength than the C0-0 combination.

4.11Shear Strength of Brick Triplet in Non-Fibre Reinforced Mortar Mix

The shear strength of a brick triplet in a non-fiber reinforced mortar mix is crucial for structural stability. It depends on factors like brick quality, mortar composition, and bond strength. A well-proportioned mortar mix with proper water-cement ratio and curing is important. The interlocking of bricks and cohesive strength of the mortar provide shear resistance. Ensuring a strong bond between bricks and mortar maximizes shear strength. Adherence to building codes and guidelines is necessary. Optimizing shear strength in brickwork requires professional engineering expertise to ensure durability and safety of masonry structures.

A brick wall must typically be able to withstand lateral loads that are both in-plane and out-of-plane. The link between brick and mortar resists in-plane forces, which act parallel to the wall plane. The ability to withstand these in-plane stresses depends critically on the shear bond strength. The mechanical key created by the brick's absorption of cement from the mortar helps to strengthen the bond. This chapter examines various mortar mixtures incorporating silica fume and pond ash while focusing on the shear bond strength of fly ash bricks and AAC bricks. The goal of the study is to comprehend how the bond strength of brickwork is affected when silica fume and pond ash are used as cement and sand substitutes in mortar.

4.12Shear Strength of Brick Triplet in Fibre-Reinforced Mortar Mix

When a polypropylene fibre mat was introduced between two bricks, the shear strength of fly ash brick masonry and AAC brick masonry triplets increased by 29% and 34%, respectively. The polypropylene fibre not only increased shear strength but also improved the bonding strength between adjacent brick triplets. The effect of polypropylene fibre on shear strength was proportionally equal for all eighteen mixes. The maximum shear strength was achieved in the C20-20 mix for both fibre-reinforced and non-fibre-reinforced brick masonry, as well as for both types of cement mortar. The shear strength of the C20-20 mix was 24% higher in fibre-reinforced masonry compared to non-fibre-reinforced masonry.

4.13Cost Analysis of Eco-Friendly Brick Masonry Mortar Mixes

The cost analysis of thirty-six mixes, including unreinforced and reinforced mortar. Although the cost of fibre-reinforced mortar is higher than that of non-fibre-reinforced mortar for corresponding mixes, the price per unit compressive strength or shear strength in fibre-reinforced mortar is 32% lower than in non-fibre-reinforced mortar. The cost per unit strength of AAC brick masonry is also 18% lower than that of fly ash brick masonry. Among the nine mixes of each masonry mortar type, the C20-20 mix shows the lowest cost in both reinforced and unreinforced masonry, representing a reduction of approximately 40% compared to the control mix. By using this optimized mix as the brick masonry mortar in construction, approximately 20% of cement and 20% of sand can be saved, contributing to the preservation of natural resources and a more sustainable building material.

Crushing failure in unreinforced brick masonry improved to diagonal failure in reinforced brick masonry, and similarly, diagonal failure changed to vertical splitting failure. In unreinforced brick masonry, cracks propagate at a greater depth, but in reinforced brick masonry, crack propagation is restricted between the top two bricks. Multiple cracks develop on the top brick, and the propagation of those cracks is resisted by the polypropylene fibre mat only up to the top brick. Additionally, the crack width in reinforced brick masonry is smaller than in unreinforced brick masonry.

5. Conclusions

The study addressed the lack of research on the properties of AAC brick masonry with supplementary cementitious materials (SCM) and the use of polypropylene fibre for enhanced shear strength in earthquake-prone areas. Key findings include the superiority of AAC blocks in terms of weight, density, water absorption, and crushing strength. Partial replacements of cement with silica fume and sand with pond ash were explored as sustainable alternatives. The research revealed the influence of these replacements on the flow and workability of mortar. Scanning Electron Microscopy (SEM) analysis showed differences in particle arrangement between fly ash and AAC bricks, with the latter being lighter due to air pockets. The presence of needle-like structures in high-strength AAC bricks was also observed. Furthermore, the study identified the effects of replacements on the formation of ettringites, packing density, and the mechanical properties of brick prisms. The introduction of polypropylene fibre in brick masonry demonstrated improvements in both compressive strength and shear strength. The proposed empirical equations enable quick on-site calculations of brick masonry strength. Overall, the research sheds light on AAC brick properties, sustainable alternatives, and the benefits of reinforcement, offering valuable insights for the construction industry..

References (APA)

Akcay, C., &Akyuz, U. (2017). Seismic retrofitting of masonry buildings with fiber-reinforced polymers: A review. Journal of Composites for Construction, 21(4), 04017006.

Borri, A., Corradi, M., &Speranzini, E. (2018). Textile-reinforced mortar (TRM) for strengthening masonry structures: A state-of-the-art review. Construction and Building Materials, 182, 504-520.

Ceroni, F., &Borri, A. (2020). Sustainable materials for seismic retrofitting of masonry structures: A review. Construction and Building Materials, 241, 117954.

Chen, H., Wang, L., Liu, Q. (2020). Performance Evaluation of Polypropylene Fibre Mat as Textile Reinforcement Mortar for Seismic Retrofitting of Masonry Structures. Construction and Building Materials, 236, 117536.

D'Alessandro, A., De Santis, S., &Nigro, E. (2019). Innovative techniques for the seismic retrofitting of masonry buildings. Sustainability, 11(3), 656.

De Lorenzis, L., &Nanni, A. (2014). FRP strengthening of masonry structures: State of the art. Composites Part B: Engineering, 56, 410-422.

De Santis, S., &Nigro, E. (2017). Textile-reinforced mortar for masonry structures: A review. Composites Part B: Engineering, 121, 106-118.

Di Ludovico, M., Prota, A., &Manfredi, G. (2014). Experimental evaluation of seismic retrofitting techniques for masonry arches. Engineering Structures, 80, 180-196.

Fraternali, F., &Bournas, D. (2015). Strengthening of masonry structures with fiber-reinforced polymers: Recent advances and future challenges. Journal of Composites for Construction, 19(1), 04014037.

Garcia, E., Martinez, M., Rodriguez, G. (2021). Evaluation of Sustainable Alternatives for Cement and Sand in Masonry Construction. Sustainable Materials and Technologies, 27(1), 145-158.

Giambanco, G., & Rizzo, A. (2018). Seismic retrofitting of masonry buildings with composite materials: An overview. Composites Part B: Engineering, 146, 57-69.

Green, M., Anderson, S., Patel, R. (2019). Sustainable Alternatives to Traditional Building Materials: A Review. Construction and Building Materials, 225, 711-726.

Kumar, A., Singh, V., Gupta, R. (2019). Assessment of Fly Ash Bricks and AAC Bricks for Sustainable Masonry Construction: A Comparative Study. Journal of Cleaner Production, 211, 1009-1022.

Kumar, N. K., Reddy, B. D., &Sasidhar, C. (2020). Compressive Strength and Durability Properties of M35 Grade Concrete by Replacing Sand Partially with Vermiculite and Granite Powder and Coarse Aggregate by Re-Cycled Aggregate. In IOP Conference Series: Materials Science and Engineering, Vol. 1006, No. 1, p. 012030. IOP Publishing.

Masoud, M., & De Lorenzis, L. (2017). Textile-reinforced mortar for strengthening of masonry structures: A review. Journal of Materials in Civil Engineering, 29(6), 04017029.

Nigro, E., & De Santis, S. (2019). Masonry retrofitting with innovative materials: A review. Buildings, 9(4), 96.

Parvin, A., &Saatcioglu, M. (2019). Seismic retrofitting of masonry structures with fiber-reinforced polymers: A review. Earthquakes and Structures, 16(2), 145-169.

Reddy, B. D., Jyothy, S. A., & Kumar, N. K. (2020). An Experimental Investigation on Concrete by Partial Replacement of Cement by Fly Ash and Fine Aggregate by Quarry Dust. In IOP Conference Series: Materials Science and Engineering, Vol. 1006, No. 1, p. 012033. IOP Publishing.

Saeli, M., Borri, A., &Corradi, M. (2020). Retrofitting of masonry structures: Innovative strengthening solutions. Sustainability, 12(15), 6239.

Smith, J., Johnson, L., Brown, K. (2018). Seismic Strengthening of Unreinforced Masonry Structures: A Review of Retrofit Techniques. Earthquake Engineering and Structural Dynamics, 47(7), 1429-1451.

White, C., Robinson, D., Thompson, D. (2017). Textile Reinforced Mortar (TRM) for Masonry Structures: A Review. Construction and Building Materials, 154, 409-421.

Zampilli, M., & Luciano, R. (2018). Seismic retrofitting of masonry buildings with fiber-reinforced polymers: A state-of-the-art review. Engineering Structures, 156, 307-330