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Use of natural fibrous plaster for improving the out of plane lateral resistance of mortarless interlocked masonry walling

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HIGHLIGHTS

- Use of natural fibres in plaster on mortarless walling was evaluated.
- Unplastered, plain and fibrous plastered samples were compared.
- Both sisal fibres and rice straws were employed.
- Considerable improvement in out of plane behavior was observed.

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ABSTRACT

Previous studies had shown that the addition of fibres to masonry elements, (i.e. blocks, mortar and plaster), improved their mechanical properties compressive, shear and tensile strength by factors of typically 0.50, 4.25 and 3.0 respectively. The use of natural fibres within plaster did more to enhance the wall strength than fibres within blocks or mortar. In this study, the effectiveness of natural fibrous plaster for improving the out of plane lateral resistance of mortarless interlocked masonry walling was evaluated. Using 1.5 m high columns, the comparisons of mechanical parameters (like elastic stiffness, first crack load, and toughness index) were carried out. Experimental work was concentrated on fibrous plasters. Non-plastered, plain-plastered and fibrous-plastered masonry columns were compared, using both sisal fibres and rice straw. The factor of increase in failure loads over unplastered columns was found to be up to 5 times for plain and up to 21 times for fibrous plastering.

1. Introduction

Masonry has been employed as a major construction technique throughout the human history [6]. A vast variety of masonry buildings exist around the globe, depending on resources and tradition. Masonry can be expected to continue to be of main importance due to its design ease and economy. However, masonry possesses some shortcomings like low resistance to bending, tension and shear forces [22]. Moreover, unreinforced masonry (URM) structures have low capacity to resist lateral loading like earthquake. Under seismic condition, URM underwent inelastic failure that could lead to a complete failure of structure [7]. Much research had been undertaken regarding the inclusion of strong and durable fibres (such as glass, steel, plastics) in cementitious materials [18,8,19]. These fibres were used in different sizes and were tested for different mechanical parameters. But using widely available natural fibres in combination with the very lean cementitious mixes (stabilized soil) has rarely been considered. In masonry, economy also demands minimum use of cement mortar. In some cases, masonry blocks are interlocked instead of being mortared to prevent sliding failure. Masonry walling usually comprises of three main components namely bricks, mortar and plaster. It is important to identify the best technique (i.e. adding fibres to which component) for improving the resistance of masonry to vertical and lateral loads. For this, various failure types need to be researched. In different studies, experimental works were carried out ranging from full scale to masonry prisms/wallets. Several different types of failures were observed depending upon the category of loading, choice of material and geometric form. The following three failure

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types were leading: friction/sliding failure, rocking and diagonal shear failure. The shear and tensile strengths of masonry require improvement to avoid these types of failures. In different studies, natural fibres have been used within soil blocks to enhance their mechanical and physical properties. Research findings from different sources are summarized in the Table 1. The use of fibres within soil blocks had some limitations. Their use was limited to compressed earth block or cement-stabilized blocks. The fibres cannot be used in fired clay bricks. A fibre content of more than 5% resulted in the reduction of compressive strength due to decrease in density, whereas, the inclusion of less than 5% of fibres could increase compressive strength by up to 10% [10]. The optimum volume of fibres in a composite was limited (by workability requirements) to 1.5–2% [10]. Decay of natural fibres could create pores/air voids within blocks which could result in a decrease in strength over time. In the literature, the durability of fibres and its improvement was reported to have been explored only over short periods of time i.e. in days rather than in years. The failure of block/brick was not normally the leading failure type in a masonry structure. It was apparent that the addition of natural fibres within soil blocks/bricks contributed little to the long-term strength and durability of walling.

Emami [6] carried out experimental investigations into different type of brick masonry to find its shear capacity, using diagonal compression and shear triplet tests. The outcome of both tests showed that shear capacity depended completely on the strength of the mortar used. The interaction between mortar and brick was considered a prime factor for long term strength of masonry construction. The parameters which could affect this interaction were mortar strength, brick strength and joint thickness [23]. Zhu and Chung [23] showed that 150% bond strength increased by adding fibres (0.5% by cement mass) in the mortar for tensile effect. Park [18] researched that cement reinforced with 3 mm long carbon fibres (5% in volume) increased the tensile resistance by more than three times, and the bending resistance by just under three times. The effect of including wheat fibres in mortar for one directional axial compressive and three-point bending load was researched by Albahttiti and Rasheed [2]. Various prism and cube models were experimentally evaluated. Their conclusion was that the fibres addition resulted in the ultimate load being enhanced by 15–27% as compared to that of sample without fibres. The natural fibres addition to cementitious material also increased its toughness. This increase in toughness occurred due to the phenomenon of fibre bridging. The toughness of composite was reported 2–6% more than plain cement paste [21]. It was determined that the use of fibres within mortar could increase the load-carrying strength of a mortared masonry structure.

Masonry walls strengthened by fibres in plaster had also been evaluated in many studies. In a study by Menna [15], plaster walls were strengthened by hemp fibre composite. Shear test using diagonal compression technique was considered for these walls and compared with unstrengthened walls. It was found to reveal five times increase in shear capacity. This improvement was more than that observed when fibrous mortar was used in masonry. Results from other studies are given in the Table 2. In the research by Di Bella [24] three lime plasters were evaluated. Synthetic fibres (polypropylene) and natural fibres (sisal and kenaf) were used as reinforcement. Comparison of plaster reinforced with artificial and natural fibres was carried out rather than plaster without fibres. It was found that the natural fibres could raise tensile capacity and could decrease cracks due to plastic shrinkage. Degradation of plaster material when exposed to freeze/thaw cycles could happen regardless of type of fibre used. This study lacked the information of comparison between plaster reinforced with and without fibre. It could benefit in decision of using fibres within plaster. Failure type and crack pattern in all strengthened panels were found different from the control panels. In control panels, stair stepped cracking was noticed, while in strengthened panels, uniform crack pattern was found in the direction of diagonal loading.

It is evident from the above-mentioned studies that the use of fibres within plaster is a better technique for enhancing the strength of masonry structure than adding fibre to either blocks or mortar. Moreover, the addition of fibre in plaster is easier to add than in blocks or mortar. However, the lack of durability of natural fibres when repeatedly wetted may exclude their inclusion in external renders. In the current experimental work on mortarless interlocked walling, the use of natural fibres is limited to inclusion in wall-plaster. The primary focus chosen is the ability of

Table 1
Natural fibres within soil blocks.

Fibre	Contents	Composite	Variables investigated	Main findings	Author
Coir	25, 50 & 75 mm; 1%, 2%, 3% & 5% by mass.	Concrete	Mechanical and dynamic properties	50 mm fibres @ 5% content gave overall optimum mechanical strengths. Improved dynamic properties: higher damping ratio, lower fundamental frequency and decreased dynamic modulus of elasticity were also found.	Ali [1]
Straw	10–60 mm 0–3.5% by mass	Soil blocks	Shrinkage. Compressive, shear & flexural strength.	10–20% increase in compressive strength. Small decreases in shrinkage, increase in flexural and shear strength.	Bouhicha [3]
Multiple fibres		Soil blocks	Compressive, tensile and flexural strength	Fibres doubled the strength of soil, Fibre-effectiveness dependent on soil matrix.	Danso [5]
Lechuguilla	25 & 50 mm fibres; 0.25–1.0% by vol.	Concrete blocks (730 × 340 × 130 mm)	Compressive and splitting tensile strength	10% higher compressive strength for short length fibre, first cracking load capacities enhanced up to 2.65 times.	Juarez [10]
Grass species		Clay and cementitious mortars	Shrinkage, tensile strength and elastic modulus	Cracking in clay delayed by 5 h and crack width reduced from 5 mm to 0.5 mm.	King [11]
Hibiscus	60–80 mm, 0.8% by weight	adobe blocks formed at 2 MPa	Compressive and (3-point) bending test	Shorter fibres more effective than longer ones. Max compressive strength increase was 16%.	Millogo [13]
Sisal	20 mm & 50 mm, 0.5% by weight	Compressed earth blocks	Tensile strength	Improved tensile strength and enhanced post cracking behavior.	Mesbah [14]
Coir and sugar cane	1.5% by vol.	Concrete	Compressive & splitting tensile strength, mod of rupture	Increase strengths at early curing stage.	Juarez [10]