MECHANICAL PROPERTIES OF FIBRE-REINFORCED MUD BRICKS

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مُسْتَخْلَص

المنشآت الترابية تم أستخدامها منذ آلاف السنين في كثير من الدول حول العالم، بما فيها السودان. المؤلفون يؤمنون باهمية هذا النوع من التشيد و انه يمكن تحسينه ليمثل بديل افضل من معظم الأنواع المستخدمة حالياً ذات المحتوي العالي من الكربون. هذة الورقة تبحث سلوك الطوب الطيني المحسن بالألياف تحت تاثير الأحمال الإنشائية. الألياف الطبيعية المستخدمة تضمن ريش الدجاج و قصب السكر. العديد من اختبارات الضغط تم إجرائها بغرض دراسة تأثير هذة الإضافات على خواص الطوب الطيني. ثلاث علاقات تجريبية لكل نوع من الألياف الطبيعية تم اقتراحها في هذة الدراسة. هذة العلاقات تشمل منحنيات الاجهاد والانفعال، معادلات تجريبية تمثل العلاقة بين كثافة و مقاومة الطوب الطيني الجديد المحسن مع كمية الألياف الطبيعية المستخدمة. هذة المعادلات التجريبية يمكن أن تؤخذ بعين الاعتبار عند التصميم وهي كذلك مناسبة للاستخدام في برامج التصميم والتحليل الإنشائي. تظهر نتائج هذة الدراسة إمكانية استخدام ريش الدجاج و قصب السكر كمصدر للألياف الطبيعية في صناعة الطوب الطيني.

ABSTRACT

Earth construction has been successfully practiced for millennia in many parts of the world, including Sudan. The authors believe that this form of construction can be readily upgraded, and that it represents a sustainable, viable alternative that avoids the use of energy intensive, high carbon content materials. This study investigates the response of fibre-reinforced mud bricks under loading. The fibre sources investigated include chicken feathers and sugarcane bagasse. Extensive compression tests were carried out on representative brick samples incorporating these materials for the purpose of understanding the effect of fibre content on the properties of modified mud bricks. Three empirically-derived relations for different fibre types are proposed. These relations include stress-strain curves that take into account limit state and compressive strengths for fibre-reinforced mud bricks, plus empirical correlation between the brick strength, brick density and fibre content, to be used in future design procedures. The developed relations are suitable for use in commercially available finite element software packages such as ABAQUS. The findings presented demonstrate that sugarcane bagasse and chicken feathers fibres are feasible options for mud brick reinforcement.

Keywords: *Sustainable earth construction; Fibre-reinforced mud bricks; Compressive strength; Mechanical properties; Chicken feathers; Sugarcane bagasse.*

1 Introduction

Mud bricks have different name in different locations, like "thobe" in North Africa and "adobe" in Central America [1]. In early times, bricks were mud made and sun dried, which made them fragile materials. Sophisticated production of bricks can be traced back to the industrial revolution in the 1760's. Since then, bricks have been used widely, all over the world, due to its various desirable properties, particularly, its remarkable mechanical, physical and thermal characteristics [2].

However, bricks are currently not competitive and are outperformed by many materials such as concrete [3]. Moreover, brick industry is criticised for its negative impacts on the environment. Besides its low quality, the main weakness of mud bricks is their affinity for water. As a result, it is necessary to improve the properties of bricks. One way of doing this is through the addition of natural fibres.

1.1 Fibre-reinforced bricks

Fibres can be divided into two main categories: natural fibres and synthetic fibres. There are two sources of natural fibre; plant-based, e.g., seed, leaves, canes, straw and wood, and animal-based, e.g., sheep wool and chicken feathers.

One of the most important and widely used seed fibres is rice husk ash. Using rice husk ash as an additive in mud bricks began in 1982, when Carter et al. [4] studied the mechanical properties of hand-made bricks made by adding unground rice husks into clay-water mixture. Rice husk ash was then studied further by many research. In 2013, Görhan and Simsek [5] recycled rice husk by volume (5%, 10% and 15%) into clay mixture. They concluded that the compressive strength of obtained bricks increases with increase in rice husk content. They also found that 10% rice husk is optimum for clay brick making. This was also confirmed by Eliche-Quesada et al. [6] in 2016. However, increase in water absorption for brick specimens with rice husk was recorded by Tonnayopas et al. [7].

Leaf fibres such as vine shoot, olive mill residue, palm, grewia optiva, pinus roxburghii and hibiscus cannabinus are well investigated [8-14]. Leaf fibres have been used for decades and proven to produce bricks with relatively high thermal insulation effectiveness and reduced bulk density [15].

The most popular cane fibre is sugarcane bagasse. Several studies on the utilization of sugarcane bagasse to enhance mud brick properties exists [16, 17]. However, findings from these studies are limited because they only investigated samples containing up to 5% by weight of sugarcane bagasse. Generally, the results reported in literature show that the reuse of sugarcane bagasse in clay bricks is feasible and has the potential of producing lightweight clay brick with improved strength and durability [18, 19].

Recently, there has been studies undertaken to study the effect of incorporating straw fibres in clay bricks. Aouba et al. [13] proposed mixing of wheat straw residues with clay to make brick samples with acceptable compressive strength and water absorption. However, Calatana et al. [20] reported that bulk density, modulus of rupture and linear shrinkage decreases with increased corn cob addition.

Another plant-based fibres that has been well studied is wood fibres. In 2005, Demir et al. [21] studied the effect of kraft pulp residues on manufacturing clay-based bricks. The results of their experiments show that this fibre can be used in clay bricks as an organic pore-forming agent due to its organic nature.

The idea of incorporating animal fibres into mud bricks was first proposed by Galán-Marín et al. [22]. Using wool as reinforcement was the main focus of their study. They reported that the incorporation of wool fibre increases the compressive strength by 37% compared to conventional clay-based bricks. In 2012, Aymerich et al. [23] extended this trend further by producing mud bricks with sheep wool. They concluded that addition of wool fibres improves the flexural strength and ductility of the bricks. It should be noted that wool fibre is the only animal fibre studied in literature till date.
Synthetic fibre has also been used and proven to be a good foaming agent. In 2003, this fibre was studied by Veiseh and Yousefi [24]. They pointed out that strength and density of the bricks decreases with increase polystyrene content.
Although synthetic fibres are strong, elastic and durable products, their manufacturing may not be environmental-friendly process. Therefore, this work is focused on using natural fibres such as chicken feathers and sugarcane bagasse.

1.2 Mechanical characteristics

The main limitation of previous research is that it has been limited in obtaining the optimum fibre content without considering the full response of mud bricks. To overcome this limitation, Turnšek and Cacovic in 1970 [25] defined a stress-strain relationship for a brick wall obtained by regression analysis of fifty-seven tests on walls. this is one of the first model proposed for stress-strain relationship for mud bricks.
The compression and thermal conductivity tests for five different mud brick mixtures were studied by Yetgin et al. [26]. The results were presented in the form of stress–strain graphs. Additional outcome of their work was the determination of the effect of varying fibre content on workability and unit weight. It was found that as fibre content increases, compressive strength decreases and shrinkage rate increases. Establishing the mechanical properties of mud bricks through experimental work recently gained attention. This is motivated by the fact

that detailed information regarding mud brick construction is not available [27-32].

1.3 Aims and objectives

The aim of this study is to develop new type of mud bricks with improved mechanical properties by using chicken feathers (CF) and sugarcane bagasse (SB) as reinforcement. This aim will be achieved through experimental investigation of the effects of chicken feathers and sugarcane bagasse on the mechanical behavior of mud bricks.

The use of these fibres will not increase the cost of final product because feathers and bagasse are abundant in most developed and developing countries, including Sudan.

2 Materials and methods

2.1 Materials

The materials used in this work include fire clay, chicken feathers, and sugarcane bagasse. All these materials are locally sourced and available.

2.2 Preparation of specimens and testing

Five different mixes were prepared for each fibre. Chicken feathers/sugarcane bagasse (0%, 1%, 3%, 5% and 7% by total weight) were mixed with clay and dried to make sample bricks. In order to make a uniform mixture, the raw materials were mixed for five minutes using an electrical mixer. The laboratory mould is then used to make samples with a dimension of 50 × 50 × 50 mm. The samples were naturally dried under laboratory conditions for seven days until constant weight is achieved (Figure 1).

The obtained samples were tested for dry density and compressive strength according to relevant British standard EN 1052-2:2016 [33] and EN 772-13:2000 [34]. A total of 30 specimens were prepared and tested. Figure 2 displays sample reinforced with chicken feathers (3% by total weight) during and after the uniaxial compression test.

Figure 1: Dried brick samples under laboratory conditions

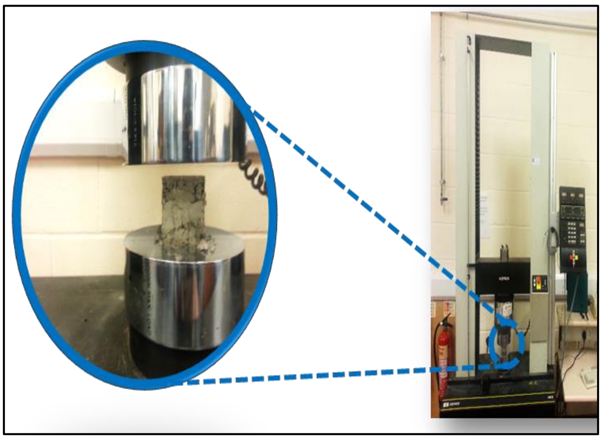

Figure 2: Chicken feathers sample during and after uniaxial compression test

3 Results and discussion

3.1 Influence of fibres on compressive strength

The control sample had lower compressive strength compared to other specimens. The compressive strength of fibre-reinforced samples increases (almost linearly) with increasing chicken feathers content and sugarcane bagasse content.

The relationship between fibre content and compressive strength is presented in Figures 3 and 4 for chicken feathers (CF) and sugarcane bagasse (SB), respectively. This relationship shows that all samples comply with the recommended values in the Methods of Test and Determination of Compressive Strength British Standard BS EN 1052-2:2016 (1-8 MPa) for unfired clay bricks (mud bricks) [33].

The tests were conducted at curing age of seven days. According to Morel and Pkla [35] and Wang and Huynh [36], higher values for compressive strength is expected with increase of time.

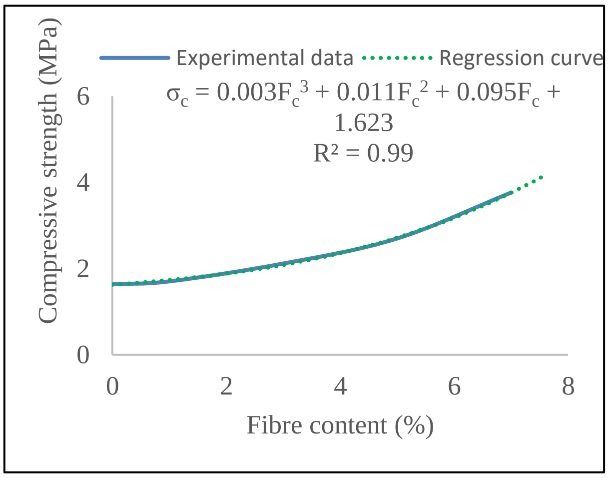

Figure 3: Compressive strength and feathers content relation for mud brick

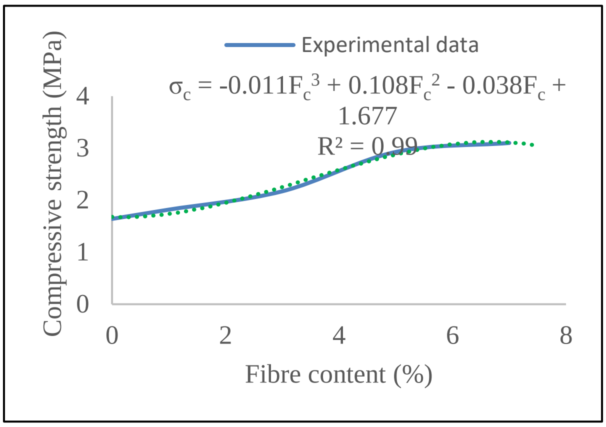

Figure 4: Compressive strength and sugarcane bagasse content relation for mud brick

Following similar approach as Illampas et al. [37] and based on experimental data obtained from uniaxial compression test, the empirical correlation between compressive strength σ_c (MPa) and fibre content Fc (%), for mud bricks, is presented in equations 1 and 2 for chicken feathers and sugarcane bagasse, respectively.

$\sigma_c = 0.003F_c^3 + 0.011F_c^2 + 0.095F_c + 1.623$ (Chicken feathers) …………………… (1)

$\sigma_c = -0.011F_c^3 + 0.108Fc^2 – 0038Fc + 1.677$ (Sugarcane bagasse) ………..…….. (2)

The main characteristic of the previous relations is that the strength is an increasing function of the fibre content as shown in Figures 3 and 4. This can be attributed to the densification in the sample as increasing fibre content improve the brick compactness.

3.2 Stress-strain relationship for mud bricks under compression

Using the results obtained so far from compression test, stress–strain relations describing mud brick response to compressive loading were developed and plotted in Figures 5 and 6.

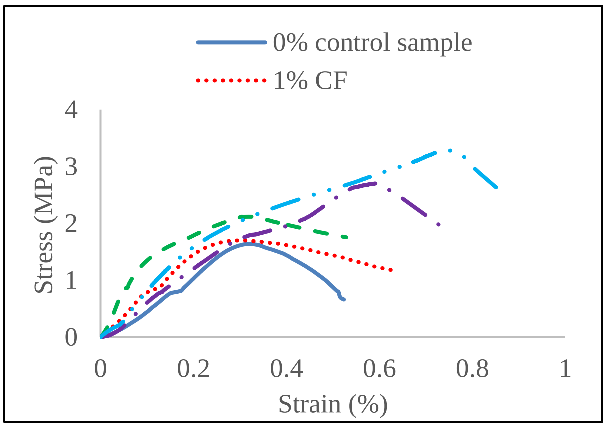

Figure 5: A stress–strain relation for mud brick with chicken feathers (CF) up to 7%

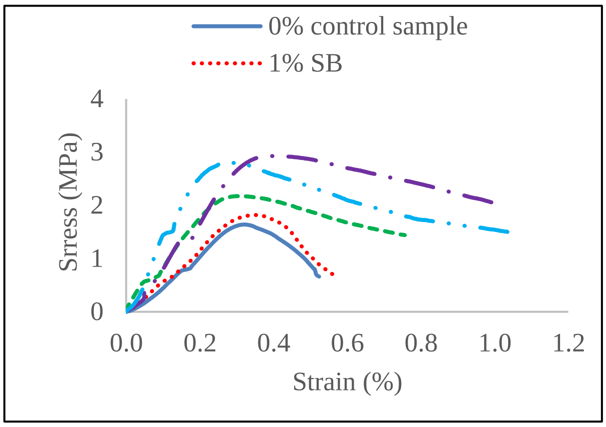

Figure 6: A stress–strain relation for mud brick with sugarcane bagasse (SB) up to 7%

All fibre-based samples show a relatively higher initial stiffness compared to that of control sample. Also, strain-softening increases with increase in fibre content. This is may be explained by increased plastic behaviour in the reinforced samples.

3.3 Density-fibre content for mud bricks

The correlation between the fibre content and density of the tested specimens was also studied. The mean density D (gm/cm^3) was plotted against the respective fibre content Fc (%). For each fibre, best-fit equations were determined for chicken feathers and sugarcane bagasse reinforced mud bricks as presented in equations 3 and 4, respectively.

$D = -0.007Fc^2 – 0.009Fc + 1.645$ (Chicken feathers) ……………………..……………(3)

$D = Fc^2 – 0.012Fc + 1.673$ (Sugarcane bagasse)……………………...…..…… (4)

It can be seen from above equations and from Figures 7 and 8 that dry density of mud bricks decreases as the amount of chicken feathers and sugarcane bagasse increases. This is possibly attributable to lower density of chicken feathers and sugarcane bagasse compared to that of clay, leading to lighter bricks [36].

It is worth noting that all empirical expressions established so far by this work are based on limited tests up to 7% by weight. Future work is required to fully understand the behaviour of these modified bricks.

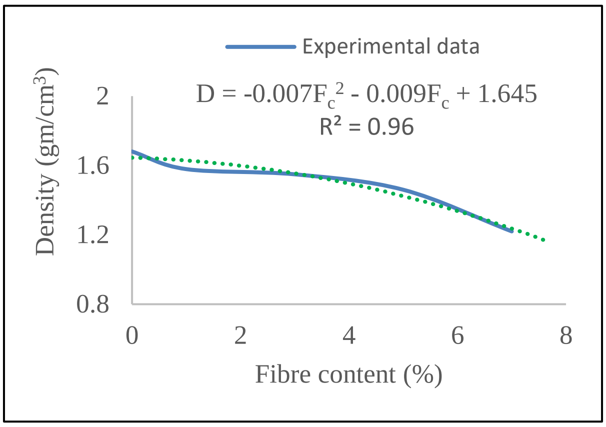

Figure 7: Density and feathers content relation for mud brick

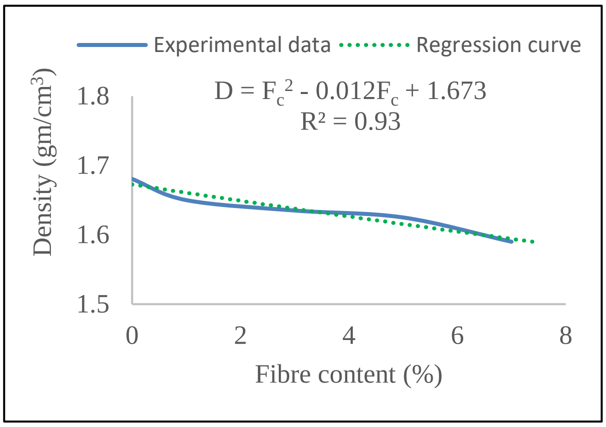

Figure 8: Density and sugarcane bagasse content relation for mud brick

4 Conclusion

The conclusions drawn from this work are as follows:

1. Empirical relation between compressive strength (σ_c) and fibre content (Fc) can be established based on the experimental results obtained so far as follows:

   $\sigma_c = 0.003F_c^3 + 0.011F_c^2 + 0.095F_c + 1.623$ for chicken feathers.

   $\sigma_c = -0.011F_c^3 + 0.108Fc^2 - 0038Fc + 1.677$ for sugarcane bagasse.

2. Empirically-derived relation between the density (D) and respective fibre content (Fc) was determined as follows:

   $D = -0.007Fc^2 - 0.009Fc + 1.645$ for chicken feathers.

   $D = Fc^2 - 0.012Fc + 1.673$ for sugarcane bagasse.

3. Inclusion of feathers and bagasse reduces brick density and improves its strength.

It should however be noted that the experimental tests conducted in this study should be simulated using finite element software, e.g. ABAQUS/ CAE, to validate the accuracy of proposed equations.

ACKNOWLEDGMENT

The authors gratefully acknowledge the research support fund provided by the Sudanese Ministry of Higher Education, Faculty of Engineering, University of Khartoum and School of Engineering, University of Aberdeen, United Kingdom.

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