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# Strength and Erosion Resistance of Spinifex Fibre Reinforced Mudbrick

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**Abstract:** This study assesses the usability of natural materials available in Australia's remote communities for making fibre-reinforced mudbricks. The present construction cost for housing in remote areas is too high to maintain the level of housing required for the remote Australian population. As this includes mostly First Nations communities, more culturally appropriate housing materials and construction methods are being considered. This study looks at mudbricks made from laterite soil reinforced by spinifex fibre, both available in abundance in remote communities. Hence, this material is more acceptable to communities as it is more sustainable, and the construction methods are more suited for First Nations engagement. Various mixes were tested for compressive strength and erosion resistance. Results suggest that spinifex can significantly improve compressive strength and reduce erosion effects; however, spinifex showed adverse effects at the early stage of the spray test. The results satisfy the minimum strength and erosion resistance requirements for construction and suggest that spinifex-reinforced mudbricks could potentially be considered as an alternative material in remote housing.

**Keywords:** mudbrick; remote housing; spinifex; natural fibre reinforced bricks; appropriate housing material

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## 1. Introduction

Construction in remote communities has been discussed extensively [1]. Despite diverse views on the sources of issues and solutions for these issues, different studies have a consensus about the positive impact of local engagement in alleviating these challenges. Community engagement in remote projects is deemed to generate sustainable jobs [2–4], improve adult literacy and numeracy in communities [4] and encourage physical activities in communities [5–7].

Producing local materials through local businesses and using these materials in remote housing could generate a variety of advantages for communities and external workers. Most importantly, it could improve communities' engagement in construction projects. It also could support local people financially and enhance intergenerational knowledge exchange [8], sustainability [9] and both-way learning [10–12] in communities. Some local materials have strong ties with Indigenous culture and thus would receive better acceptance by the local people. For example, Indigenous people of Australia traditionally use fibrous materials [13], such as spinifex [14] and termite mounds [15], for making tools or in buildings [16]. In this regard, mudbricks made from local soil and spinifex seem to receive acceptance from local people. This acceptance is an essential element in the success of remote housing projects considering Indigenous spirituality and connection to the land [17].

There are many further issues with the houses that are constructed in Australia's remote communities, such as the low quality of maintenance, the short lifespan of houses [1,18–20] and poor health conditions [21–23]. These issues have not been resolved after many years of policymaking, partly due to the lack of verification of the alternatives proposed.

In recent decades, as the sustainability paradigm has gained momentum, the mudbrick, which has a long history in construction [24], has received attention in developed countries [24–26] and is advocated by the government [27] and technical societies [28,29]. From a technical point of view, the durability of mudbricks has been a significant concern, and a large body of research on mudbricks has been formed around the environmental effects on mudbricks [30]. Further, sediment coatings and infillings, abrasion due to wind flow, puddling and bioturbation could cause damage to mudbricks [31]. Long-term experiments on mudbricks and historic buildings made of mudbrick clearly show that durable and reliable buildings could be built from mudbricks [32–34].

Research showed that erosion is the leading cause of damage to earth structures in regions with high precipitation frequency and intensity. Erosion resistance is a critical material property in NT remote areas due to heavy rain and severe wind [35,36]. Two mechanisms have been suggested for the erosion of earth structures under rainfall: damage due to the kinematic energy of raindrop impact and turbulent flow along microwater streams on the surface of the bricks [37]. Surface protection [32–34] and strengthening brick materials could be considered to tackle erosion. The strengthening of the mudbrick material could be achieved by adding stabilisers such as hydraulic lime, cement, fly ash, etc., and/or by including (primarily natural) fibres in the mix [38–43]. The latter is the focus of this study, and spinifex is used for this purpose. Erosion resistance assessments can be performed through drip tests, including the Geelong method [44] and Swinburne Accelerated Erosion Test (SAET), the Accelerated Erosion Test [45] and brush wire test [46,47]. Drip tests are not recommended for areas with rainfall greater than 500 mm per annum [30]. This is due to turbulent erosion [37] in such areas. According to the recommended setup in [48], the spray method was employed for erosion tests. Soil selection, preparation and details of tests conducted in the study are discussed in the following sections.

A comprehensive review on the application of fibres to improving earth properties [49] shows that natural fibres, in general, enhance compressive, tensile and shear strength [40,50] and reduce the shrinkage and maximum dry density (MDD) of earth products [51,52]. The inclusion of natural fibres in earth products has increased the water content in the mix [53,54]. The higher water content of the mix and relatively lower density of natural fibres decrease the MDD of the fibre-reinforced earth products. The decline of the MDD typically causes the decline of soil mechanical properties [55]. However, property enhancement because of the inclusion of fibres well compensates for the decline of the MDD in fibre reinforced earth.

Further, a lower MDD means a lower total weight of the structure. Fibre reinforcement also improves block ductility [56,57]. Moreover, studies show that the inclusion of natural fibres improves the thermal properties of earth blocks [58,59]. With all the advantages of natural fibre inclusion in earth products, the long-term degradability of fibres is a concern [60].

Here, the effect of spinifex on the compressive and erosion properties of mudbricks made from NT local soil has been studied. Spinifex or Tjanpi, which is called Baru by the Yindjibarndi and Ngarluma people [61], is a grass flora that is available in abundance in Australia. There are more than 25 species of spinifex in Australia [62], which could be either resinous and soft or non-resinous and hard species [63]. Traditionally, Indigenous people used spinifex for different purposes, including cladding, making shelters [22], and making nets [63]. In recent years and with the rise of the sustainability paradigm in engineering, spinifex fibre has been considered a sustainable and natural material for making composites with reasonable mechanical properties [64–66]. Figure 1 shows the appearance and location of collecting the spinifex used in this study.

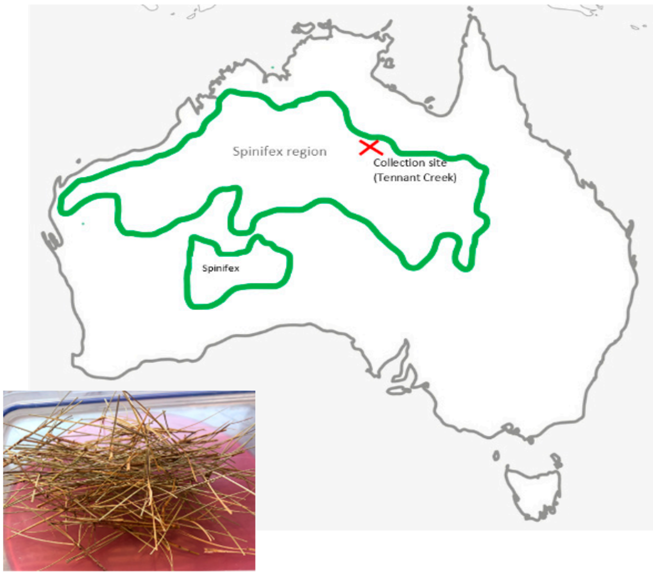


**Figure 1.** Spinifex in plant and fibre. **Top**: vegetation map of spinifex in Australia. **Bottom left**: spinifex used in this study, collected from Tennant Creek, NT, Australia.

The aim of this study is to investigate the potential improvements that the inclusion of spinifex could make in the erosion resistance of mudbrick for four different spinifex mix designs. As cement must be shipped to remote areas to reduce the dependence on external materials, the amount of cement in the mix is limited to the minimum recommended value, and spinifex is used to ensure the bricks satisfy minimum requirements. The simplicity of the brick-making process developed for these tests makes the production possible in remote communities and with local labourers.

## 2. Materials and Methods

Bricks were made in the lab by compacting the mix in the wooden moulds. An Instron 8802 Servohydraulic universal testing machine with a static loading capacity of up to 250 kN was used for compressive testing of the bricks. A spray erosion test setup was made and used according to HB 195—Australian Earth Building Handbook. These are described in more detail in the section on the testing program.

The soil was collected from the excavated face at a depth of 1500 mm to 2000 mm at the new building site of the Charles Darwin University in Darwin City, as shown in Figure 1. This is similar to the work reported in [67]. By inspection, the texture and red to brown and dark yellowish colour of the extracted soil suggested that it could be laterite, a prevalent soil in Australia's Northern Territory [68–70]. Further investigation showed that about 30% of the material seemed to be Kandosols and the rest laterite. Figure 2 shows the appearance of the extracted soil. The sieve analysis result of the soil is presented in Table 1.

Both Kandosols and laterite soils are deemed suitable for brick production [40,48,71,72], while laterite is more reactive with cement than Kandosol [73]. This property could be related to the laterite's lower silica–sesquioxide ratio. The reactivity of laterite with cement increases hydration products with C-S-H (Calcium Silicate Hydrate) bonds and improves the strength and durability of the bricks.

As recommended in [74,75], a sediment jar test was used initially to evaluate the suitability of the extracted soil, after which a sieve analysis was conducted according to [48]. The optimum water in the mix was estimated using a proctor compaction test for the soil without fibres. Actual water content was gained by incrementally adding extra water to the optimum water content acquired from the proctor test until the mix became workable.

**Figure 2.** The appearance of the soil used in this study taken from CDU's new campus building site on Cavenagh St, Darwin.

**Table 1.** Sieve analysis results.

| Sieve Size (mm) | Weight Retained on the Sieve (%) | Description |
|---|---|---|
| 4.75 | 31 | Coarse Aggregate |
| 2.36 | 5 | Sand |
| 2 | 5 | |
| 0.85 | 4 | |
| 0.425 | 3 | |
| 0.25 | 3 | |
| 0.075 | 2 | |
| Pan | 47 | Clay and Silt |

The compressive strength of the bricks was found to be linearly proportionate to the maximum dry density (MDD) [76]. Further, studies by others show that the standard proctor compaction is more suitable than the modified proctor compaction test for mudbrick production [77]. This is because manual processes are commonly involved in mudbrick production, and thus, the standard procedure is deemed more representative of the usual practice. Figure 3 shows the results of the proctor test, which suggest that the maximum density is reached at 12.5% water content. The addition of 4% extra water was necessary during the actual moulding of the bricks. Water content was kept the same in all mixes, and spinifex did not make any further demand on the water content.

The particle size distribution is essential in mudbrick production, and in this regard, the sieve analysis test [75,78] and hydrometer test [78] are suggested to evaluate the suitability of the soil for mudbrick production. Sieve analysis was carried out according to ASTM C136/C136M [79]. Three sieve analysis test trials were conducted on the extracted soil samples. Table 2 shows the recommended range of grains in the soil for different earth structures. According to [80], the 47% clay and silt component of the soil used in this study is suitable for mudbrick production.

The weight of cement to soil is recommended to be between 5% and 15% in mudbricks, according to AS 3700 [81]. Further, the maximum addition of lime of 10% [82] could improve the properties of the mudbrick through pozzolanic reactions [78,83–85]. In this study, however, General-Purpose Cement (GP) cement produced by Bastion Building Materials and widely available throughout the NT was used. The cement had around 87% Portland clinker, 2–5% gypsum, 0–7.5% limestone and 0–1% calcium, according to the manufacturer datasheet. No extra lime was added to the mix. This was intended to reduce the dependence on non-local materials. Mix proportions with respect to soil weight are listed in Table 3. While the optimum dried density was measured at about 2150 $kg/m^3$

(see Figure 3), the average density of the dried bricks without spinifex was 1840 kg/m$^3$, and the addition of spinifex had a subtle impact on the density of bricks. The difference between the optimum density and the actual density of the bricks could be associated with the addition of extra water to improve workability.

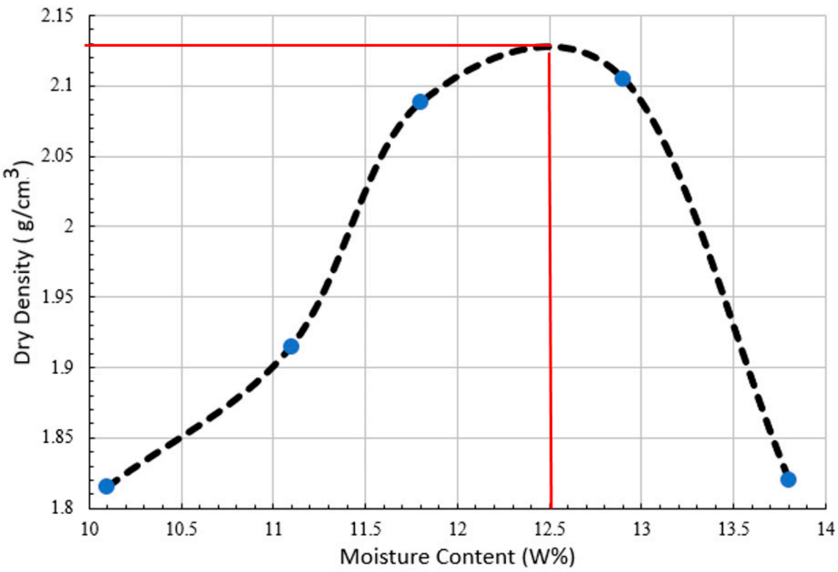


**Figure 3.** Proctor compaction results for soil mix with 5% cement (weight of cement to soil).

**Table 2.** Recommended range of particles in soil for making earth structures by [80].

| Technique | Clay (%) | Clay and Silt (%) | Sand (%) | Gravel (%) | Sand and Gravel (%) |
|---|---|---|---|---|---|
| Rammed earth | 5–20 | 15–35 | 35–80 | 0–30 | 50–80 |
| Pressed soil | 5–25 | 20–40 | 40–80 | 0–20 | 60–80 |
| Adobe | 10–30 | 20–50 | 50–80 | - | 50–80 |
| General-purpose | 15 | 35 | 60 | 5 | 65 |

**Table 3.** Materials used for making bricks.

| Materials | Weight of Material to Soil Weight (Percentage) |
|---|---|
| Soil | 100% |
| Cement | 5% |
| Water | 16.6% |
| Spinifex | 0%, 0.3%, 0.5% and 0.7% |

Spinifex was collected from Tennant Creek in Australia's Northern Territory (see Figure 1). Fibres were cut into 60 mm sections. Figure 1 shows the appearance of the fibres before being cut in size. According to HB 195 of the Australian Earth Building Handbook [48], bricks of size 76 mm × 230 mm × 110 mm were produced using the slope moulding technique. Thirty samples were made in total, of which six samples were used for finding the minimum water content, which creates enough workability for moulding the samples. Three samples from each mix and 24 samples in total were tested in compression and erosion resistance tests. The mix was kneaded in the mould and compacted in layers. Some amount of the mix water was saved and sprayed between the layers during moulding to compensate for evaporation and improve cohesion in the moulded material. Bricks were kept in moulds for 48 h, followed by curing for three weeks. Figure 4 displays some episodes of sample production.


**Figure 4.** Some episodes of brick production.

## 3. Results

The standard compressive strength test was conducted according to ASTM C1314-18 [86], and an accelerated erosion test was conducted according to [48]. In subsequent sections, details of the tests and their respective results are presented, followed by a discussion of the findings of this study.

### 3.1. Compression Test

Three samples were tested for each design mix: 0%, 0.3%, 0.5% and 0.7% (according to ASTM C1314-18 [86]. The surfaces of the bricks were cleaned and levelled, and the dimensions of the bricks were measured to the nearest 1 mm before the test. A constant rate of 2.5 mm/s compression load was applied from the top plate to the surface of the brick until failure. Figure 5 shows samples during and after loading. Table 4 summarises the compressive test results.

**Table 4.** Brick force and compressive strength.

| Weight of Spinifex to Soil (Percentage) | Mean Compression Strength (MPa) | Coefficient of Deviation (%) |
|---|---|---|
| 0% | 3.2 | 1.5 |
| 0.3% | 3.3 | 1.5 |
| 0.5% | 3.6 | 4.1 |
| 0.7% | 3.0 | 1.7 |

Load displacement was recorded during the compression test. Values of strain were obtained as the ratio of displacement to the initial height of the samples. Strain–stress diagrams and ultimate stress values are shown in Figures 6 and 7, respectively.

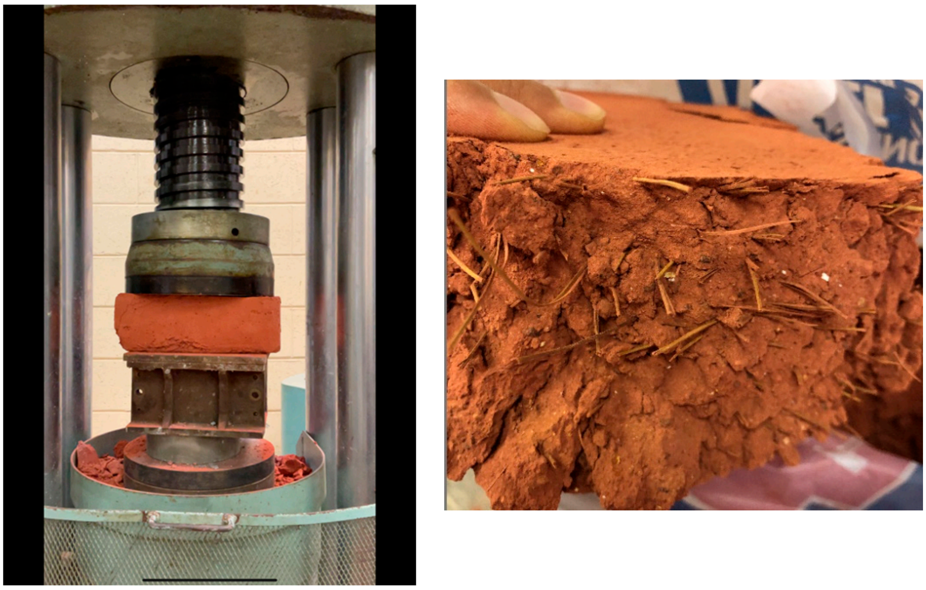

**Figure 5.** Mudbricks during and after loading.

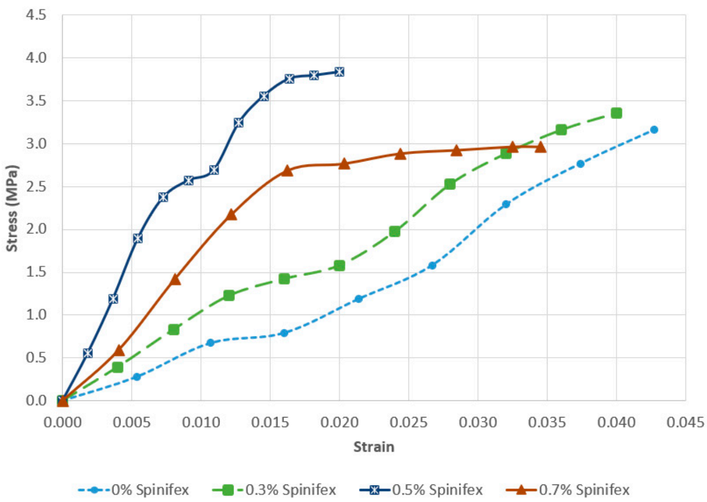


**Figure 6.** Values of stress vs. strain for different mix designs.

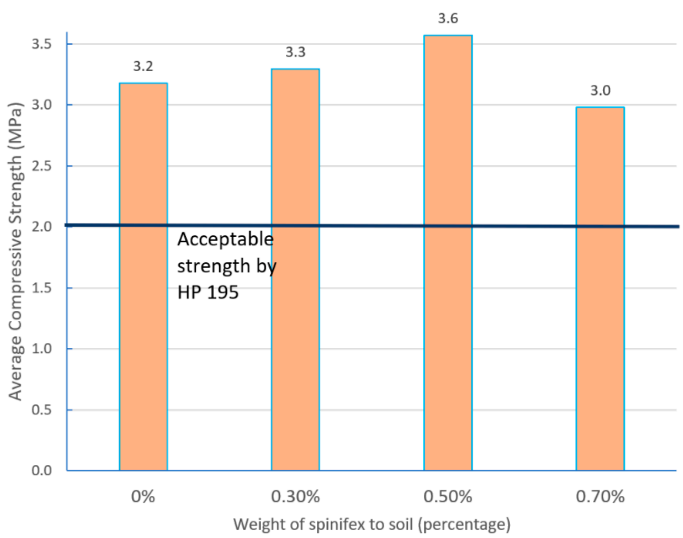


**Figure 7.** Average values of ultimate compressive strength.

As Figure 7 suggests, all design mixes satisfied the minimum compressive strength requirement of 2 MPa recommended by the Australian Earth Building Handbook [48].

### *3.2. Spray Test*

Samples were tested for erosion resistance through an accelerated erosion test according to HB 195—Australian Earth Building Handbook. The test setup used for the erosion test is displayed in Figure 8. A large number of remote communities in the NT are in the cyclonic region. For such regions, the minimum requirement for erosion resistance is D < 15 mm/h, in which D is the depth of the erosion pit in the spray test as per [48]. This criterion is graphically shown in Figure 9. All bricks were exposed to a water pressure of 50 kPa throughout an hour testing period. The depth of the pit (see Figure 8) made due to water spray was measured as well as the rate of erosion, respectively, in mm and mm/hour.

**Figure 8. Left**: test setup for accelerated erosion test. **Right**: measuring the pit depth using vernier callipers.

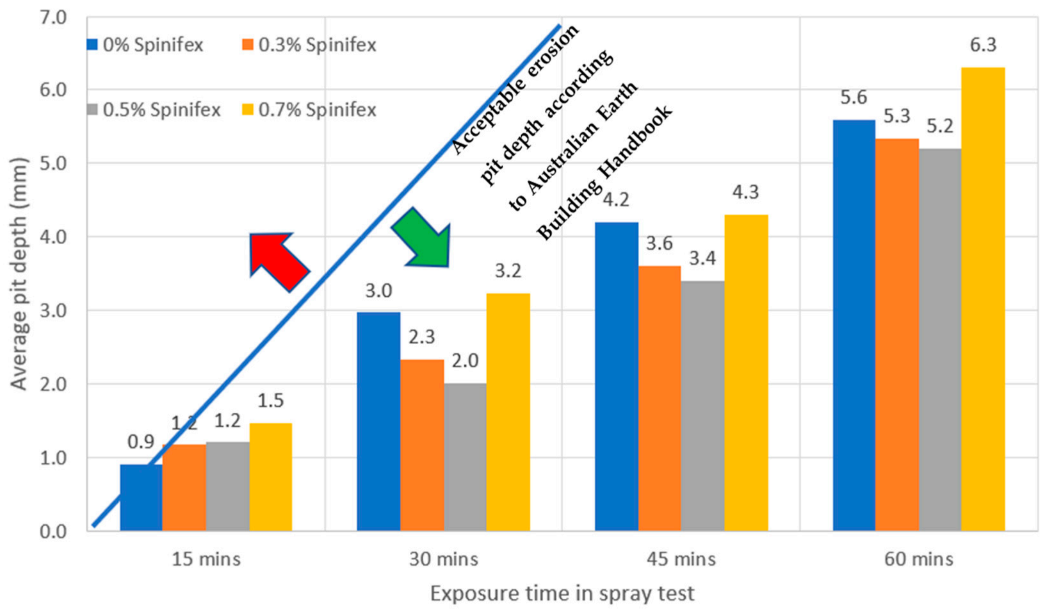


**Figure 9.** Average values of pit depth in accelerated erosion test.

The results of the erosion test for all samples are tabulated in Table 5, and the average values are graphically illustrated in Figure 9. The results suggest that all the tested mix designs met the minimum requirement of an average 0.25 mm pit depth per minute.

**Table 5.** Spray test results.

| Exposure Time in Spray Test (min) | Pit Depth (mm) | | | Mean Value (mm) | Coefficient of Deviation (%) |
|---|---|---|---|---|---|
| | | 0% Spinifex | | | |
| | Sample I | Sample II | Sample III | | |
| 15 | 0.7 | 1.1 | 0.9 | 0.9 | 18 |
| 30 | 2.6 | 3.8 | 2.5 | 3.0 | 20 |
| 45 | 3.9 | 4.2 | 4.5 | 4.2 | 6 |
| 60 | 5.4 | 5.5 | 5.9 | 5.6 | 4 |
| | | 0.3% Spinifex | | | |
| | Sample I | Sample II | Sample III | | |
| 15 | 1.1 | 1 | 1.4 | 1.2 | 15 |
| 30 | 1.7 | 2.4 | 2.9 | 2.3 | 21 |
| 45 | 3 | 3.6 | 4.2 | 3.6 | 14 |
| 60 | 3.8 | 5.6 | 6.6 | 5.3 | 22 |
| | | 0.5% Spinifex | | | |
| | Sample I | Sample II | Sample III | | |
| 15 | 1.3 | 1.1 | 1.2 | 1.2 | 7 |
| 30 | 2.3 | 2.1 | 1.6 | 2 | 15 |
| 45 | 3.3 | 3.4 | 3.5 | 3.4 | 2 |
| 60 | 5.3 | 5.2 | 5.1 | 5.2 | 2 |
| | | 0.7% Spinifex | | | |
| | Sample I | Sample II | Sample III | | |
| 15 | 1.9 | 1.3 | 1.2 | 1.5 | 21 |
| 30 | 3.2 | 3.8 | 2.7 | 3.2 | 14 |
| 45 | 4.2 | 4.2 | 4.5 | 4.3 | 3 |
| 60 | 6.4 | 6.1 | 6.4 | 6.3 | 2 |

## 4. Discussion

The literature review shows that the compressive strength of earth blocks with or without fibres and with different percentages of cement varies between 0.3 MPa and 5.5 MPa [39,87,88]. Since only 5% cement was used here, the compressive strength of 3.6 MPa gained in this study suggests that the soil used had the right quality for making mudbricks. Except for wall corners, the compressive stress in walls in remote houses, even under cyclone loads, rarely exceeds 0.5 MPa. Therefore, mudbricks could be used in remote houses from a structural point of view. Similar to [67], the applicability of the findings to the NT remote areas was highly intended in this study. Therefore, a very simple mix of natural soil with the widely available General-Purpose Portland cement and natural fibres in Australia's desert was studied. Satisfactory results, and the fact that laterite soil used in this study is the common soil type in many remote communities, suggest that mudbrick with spinifex fibres can be widely used in the central NT and other remote areas that have access to spinifex. The similarity of soil types in different communities and the simplicity of mudbrick production allow seamless knowledge exchange between communities and external people, promoting two-way learning, community engagement, and a sense of ownership of the built environment.

This study was performed in parallel to [67] and intended to explore the feasibility of using mudbricks made from local soil in remote areas of Australia's Northern Territory

(NT). Laterite soil and spinifex are widely available in remote communities. The only external material used for making the bricks was general-purpose cement, and therefore only the minimum recommended percentage of cement was used in the mix. Compressive and erosion tests were conducted on four mix designs, and the results clearly showed that the inclusion of spinifex up to 0.5% of soil weight improves the erosion resistance and compressive strength of the brick samples. The optimum amount of spinifex could change by introducing more cement in the mix, but this was not explored since the measured properties of the bricks satisfied the requirements of the Australian Earth Building Handbook, and thus the inclusion of more cement was not justified. Moreover, changing the size of the fibres from 60 mm to smaller sizes would improve the properties of the product. However, to reduce the efforts for fibre production in remote areas, a relatively large size of 60 mm was selected for the fibres.

The results in Figure 9 suggest that the fibre is ineffective in erosion resistance in the first 15 min of the spray test. To make it clearer, Figure 10 shows the percentage of erosion pit depth reduction after using spinifex. As this figure illustrates, in the first 15 min of water spray, spinifex worsened the erosion resistance, and pit depth in the samples with 0.5% spinifex performed 33% worse than samples without spinifex. By increasing the exposure time from 15 min to 30 min, the clay matrix on the surface seems affected, and there is extra resistance because the bond between the soil and the fibres seems to be mobilised. It is worth mentioning that the pit depth in the first 15 min of the exposure is less than 2 mm, and thus the brick is subtly damaged on the surface.

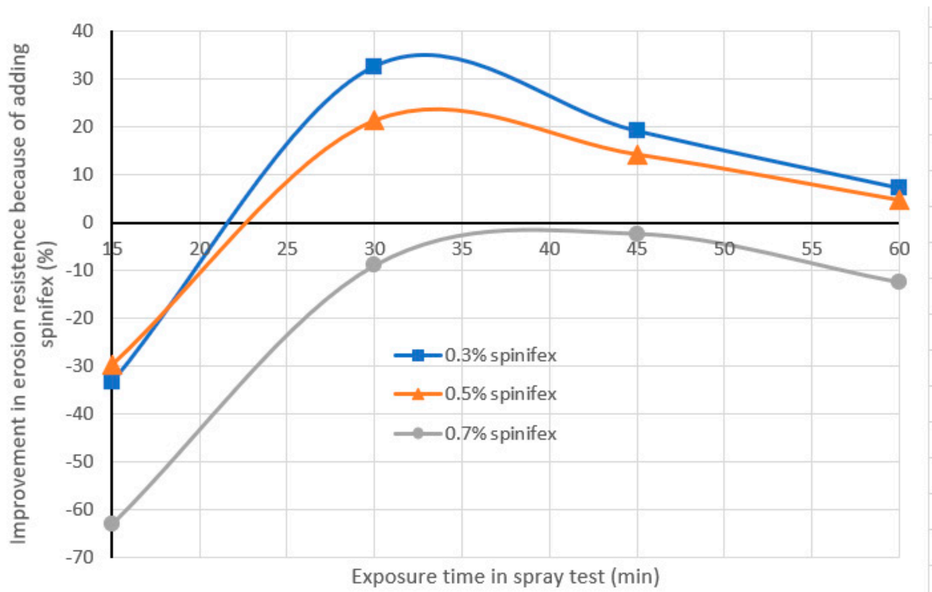


**Figure 10.** Effectiveness of spinifex inclusion in improving erosion resistance.

The improvement in erosion resistance because of using spinifex could be shown by the effect of spinifex in the reduction of pit depth. This is shown in Figure 10. The vertical axis in Figure 10 shows the percentage of reduction in pit depth during the spray test. Figure 10 shows that 0.7% spinifex negatively affects the spray test. The inclusion of 0.3% and 0.5% spinifex have an almost similar effect on the erosion resistance. By interpolating between spray test data points, Figure 10 suggests that 22 min from the start of the spray test, spinifex does not help in erosion resistance. The effect of spinifex is maximum midway through the test, i.e., 30 min, and declines to about 10% by the end of the test. Fibres used in this study were relatively long (60 mm), and shorter fibres might result in different behaviour. Also, the inclusion of more cement might change the trend in Figure 10, which could be considered in future studies.

While the addition of spinifex was found to be effective in improving the mechanical properties of mudbrick, it might invite grass-eating termites such as Nasutitermes triodiae (also known as spinifex termite) into the residence. Nasutitermes triodiae is a fast-growing species of grass feeder termite that do not attack timber but grass [89]. The mound made by this termite could exceed 4.5 m in height in about five years [90,91] and could survive for more than 80 years [92]. The potential attack of grass termites to spinifex mudbricks should be investigated before using this material in remote areas. As the results in [67] suggest, using more cement in the mix improves the mechanical and erosion resistance of the bricks. Therefore, if termite attack on the fibre is found to be serious, its usage could be lowered, and the desired properties could be achieved by the inclusion of more cement in the mix. Further, applying a local resin coating on the bricks might be a solution to protect the fibres. Indigenous people used spinifex for many applications, including roof construction [16]; thus, their knowledge of a potential treatment against termite attack to spinifex could also be consulted.

## 5. Conclusions

This study attempts to explore the suitability of mudbricks made from local materials in Australia's remote communities. Laterite soil and different percentages of spinifex fibres with the minimum recommended amount of cement were used to make mudbricks. The compressive strength test and accelerated erosion test showed satisfactory results. The following conclusions could be made based on the gained results:

- Samples with a 0.5% spinifex to soil weight showed maximum compressive strength. The average compressive strength was 3.6 MPa in these samples. This is higher than most reported compressive strengths for mudbricks and suggests the suitability of the common laterite soil in the NT for making mudbricks.
- The inclusion of spinifex greater than 0.5% of soil weight was found to have a negative impact on both compressive strength and erosion resistance.
- Erosion resistance test results suggest that spinifex had a negative impact on erosion resistance until around 22 min from the start of the spray test, which is equivalent to approximately 2 mm of erosion pit depth.
- Spinifex was found to be more effective in improving the erosion resistance in the first half of the testing (before 30 min). This could be attributed to the loss of the matrix bond with fibres during the test.
- While the use of spinifex was found to be effective in improving the strength of mudbricks, it could cause grass-eating termite damage to the residence.
- Spinifex has been used by the First Nations people for thousands of years to make different items. So, their knowledge could be used in future work to improve the performance of construction materials made with spinifex.

For the long-term lifespan of construction materials, spinifex in mudbricks has a positive impact. The inclusion of spinifex up to 0.5% of soil weight was found to positively impact erosion resistance after 22 min of the spray test and when the pit depth was greater than 2 mm. The inclusion of spinifex ultimately reduced the erosion pit depth by 34%.

At the same time, using mudbrick does not seem to introduce seismic resistance problems in most remote communities. Construction technologies employing ductile materials, which can deform without sacrificing strength, and those utilising materials that reduce seismic forces by reducing weight through fibre reinforcement, demonstrate enhanced resilience. Most remote communities in Australia are in low seismic risk regions, so using mudbricks with a minimum steel reinforcement is likely to satisfy the seismic design requirements. Hence, the mudbrick approach should be suitable for the Northern Territory. Further work may, however, be needed to consider the effect of termites on the fibres.

**Author Contributions:** D.G.: formal analysis, investigation, data curation, review and editing. A.R.: conceptualization, methodology, formal analysis, investigation, review and editing and supervision. M.B.: methodology, validation, review and editing and supervision. C.K.: validation, review and editing and supervision. V.S.: investigation. T.N.P.P.: validation and investigation. All authors have read and agreed to the published version of the manuscript.

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