CEMENT BONDED WOOD WOOL BOARD AS A BUILDING MATERIAL FOR LOW COST HOUSING

A.L. Mrema
Department of Structural Engineering,
University of Dar Es Salaam
P. O. Box 35131, Dar Es Salaam

This paper gives results of a preliminary study on the properties of cement bonded wood-wool boards manufactured as composites by using wood-wool (excelsior) from podocarpus spp wood species and ordinary Portland cement. Two main parameters were varied during the investigation and these were the width of the wood-wool and the cement to wood-wool ratio. Results show that the optimum mix proportion is three parts of cement to two parts of wood-wool by weight and that a smaller excelsior width gives higher board strengths. The results from tests on flexural strength, compressive strength and tensile strength far exceeded the requirements of the German Standard DIN 1101:1989. Results of water absorption and swelling were, however, higher than those specified in the standard but this was attributed to insufficient pressure on the boards during manufacture an anomaly which can be corrected. The potential uses of the boards are in basements, floor units, permanent shuttering, partitioning, sound insulation in walls, ceilings and floors, roofs, sound barriers and thermal insulation. Further research is required to investigate the use of different wood species and different mineral binders.

Keywords: *Podocarpus spp, wood-wool, wood-cement, composites*

INTRODUCTION

In developing countries where the majority of the population is poor there is a need of looking for cheap and affordable housing materials. The use of wood cement composites like wood wool cement boards, for example, has proven to be an attractive alternative to the more costly materials like concrete, sand cement blocks, steel etc. The reason seems to be that apart from its low price and its excellent properties such as high insulation value, fire resistance, termite and fungi proof, it can be produced from locally available wood and cement, but it can easily be finished with mortar, or plastered or covered with other materials such as aluminium, plastic sheets and roofing paper. It can, due to its light weight, easily be handled, so no hoisting equipment is necessary. Also it can be nailed and screwed into frames of different materials, sawn and painted (van Elten 1975).

Wood cement composites are in general strands, particles or fibres of wood mixed together with Portland cement as a mineral binder and manufactured into panels, bricks, tiles and other products used in the construction industry. Semple and Evans (2004) have extensively reviewed the use of wood cement composites. Wood cement composites (WCC) contain approximately 30-70% by weight of wood in various forms and 70-30% mineral binder (Simatupang et al 1977). Chittenden(1972) divides mineral bonded wood composites into two distinct groups: (1) composites in which wood is incorporated as an aggregate in the mineral matrix (as fibres, sawdust, shavings or particles) and (2) composites in which the cement (or other mineral binder) acts purely as a binder, such as wood-wool cement boards (WWCB) or flake boards.

Wood can serve as a low-cost filler and/or reinforcing material which greatly improve the stiffness, fracture toughness, strength to weight ratio, creep deflection and thermal and acoustic resistance of cement when incorporated into a composite bonded with cement (Goodell et al 1997). The most common types of WCC are cement bonded particleboard (CBP), wood-wool cement board (WWCB) and cement bonded fibre board (CBFB).

Wood-cement composites have much higher resistance to both decay (i.e. mould, rot, borers and termites) and to combustion than resin bonded boards or solid wood (Ramirez-Coretti et al 1998, Goodell et al 1997). Wood cement composites assume considerable importance where the technology and materials for manufacturing conventional resin bonded wood composites are expensive or unavailable (Badejo 1988, Alberto et al 2000). They can also be manufactured where available wood or plant waste resources are unsuitable for production of sawn timber or conventional resin-bonded wood composites (Ledhem et al 2000). More importantly, they are much better suited to high fire, weathering and bio-deterioration risk applications to which solid wood and resin-bonded composites are vulnerable(Dinwoodie and Paxton 1991). Cement bonded composites emits no toxic wastes during manufacture(van Elten 2000) and employ an inert binder free from health risks associated with the use of resin bonded composites(Chen and Hwang 1998).

Although Wood cement composites (WCC) have high density, the relatively low strength of WCC panels limits their use to non structural paneling or roofing applications (Oyagade et al 1995, Wolf and Gjinolli 1999). A significant advantage of wood-cement composites to engineering applications appears to lie in the ability to absorb and dissipate mechanical energy (Wolf and Gjinolli, 1977, 1999). This, as well as good sound dissipation and absorption properties, has attracted research and development of wood cement composites as very practical and cost effective highway sound barriers (Wolf and Gjinoli 1999, Lan and Huang 2000, Boothby et al 2001). Wood cement composites can be used in areas subjected to seismic activity and/or heavy wind loads such as hurricanes (Wolfe and Gjinoli 1997, 1999).

Despite their higher weight strength ratio, wood cement composites have become popular in Europe and Asia for use as exterior siding, roofing and flooring applications. Some typical external applications well suited to WCC include agricultural buildings, prefabricated and mobile buildings flat roofing, industrial and exterior domestic cladding, tunnel linings, highway sound barriers, fire barriers and paving tiles(van Elten 2000).

Products such as cement bonded particle-board (CBPB) have shown to have long service life, retaining and even increasing its strength after years of exposure. A controlled outdoor weathering test of CBPBs in Britain over 10 years by Dinwoodie and Paxton (1989) found that the strength of CBPBs increased by around 45% over the first 3 to 5 years but then declined by about the same amount over the next 5 to 7 years. Enhanced strength and durability of wood-cement composites with aging has been attributed to 'mineralisation' or'petrification' of the wood elements by cement minerals (Bentur and Ackers 1989). In a study by Sekino and Suzuki (2002) cement bonded boards showed excellent dimensional stability and only slight reduction in mechanical properties after outdoor exposure for 10 years, greatly outperforming other wood based panels.

Despite their obvious benefits compared with other types of wood panels, there are several factors that have prevented WCC from becoming more widespread (Moslemi 1989). One of the factors is the long initial and post-stress curing time of the Portland cement binder which leads to reduced production capacity and a requirement of a large inventory of boards during curing (Mallari et al 1997). The high weight to strength ratio compared with resin bonded boards has also reduced their popularity (Lee and Short 1989) despite their higher toughness and durability. The third major obstacle to further successful development of WCC industries is variation in wood compatibility with cement. There is extreme variation in compatibility among both hardwoods and softwoods with Portland cement (Hachmi and Campbell 1989) resulting in strong species specifity among potential raw materials for WCC manufacturing industries. There is no information about compatibility of many wood species or experience in converting and using them for cement bonded boards of different types.

The mechanical properties of composite materials including WCC are a direct function of the interface bonding between the reinforcing or filler fibre and the matrix and are greatly affected by the type, content, geometry and arrangement of the reinforcement or filler (Brandt 1995, Razi et al 1999). Bond strength in WCC is largely dependent on hydrogen bonding between the wood or fibre surface and the cement matrix. Surface roughness of wood flakes or strands has a positive effect on the bond strength with Portland cement (Kayahara et al 1979). The properties of WCC are significantly influenced by the content, form, arrangement and other characteristics of wood reinforcement (Kayahara et al 1979, Badejo 1988).

Strategies for improving the compatibility of wood with cement and other mineral binders and increasing the strength of WCC include modifying the wood through extractive removal, pre-treatment with chemicals and modification of wood content, form and arrangement in the composite (Kayahara et al 1979).

The compatibility of wood with cement can be strongly influenced by such factors as the season in which it is cut and the delay between cutting and use (Sudin et al 1989). The sugars and starches present in wood have been identified as the most critical compounds causing incompatibility between wood and cement especially in softwoods (Sandermann et al 1960, Davis 1966, Bruere 1996).

The cement content strongly influences board properties and an optimum cement content need to be determined to take into account the high cost of the Portland cement relative to that of the wood and its contribution to board weight (Moslemi and Pfister 1987).

The addition of cement setting accelerators also strongly influences the strength of WCC. Simple inorganic electrolytes such as $CaCl_2$ and $MgCl_2$ are among the most effective additives in counteracting the inhibitory effects of many woods during composite manufacture (Wei and Tomita 2001).

Figure 1 illustrates as an example a house made of wood-wool cement boards (WWCB) and Figure 2 shows a shredding machine which produces the wood-wool (Picture courtesy of Dr. Philip Evans, The Australian National University, 2004)

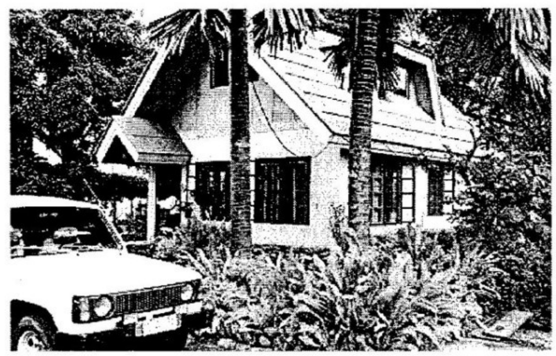

Figure 1: House made of WWCB

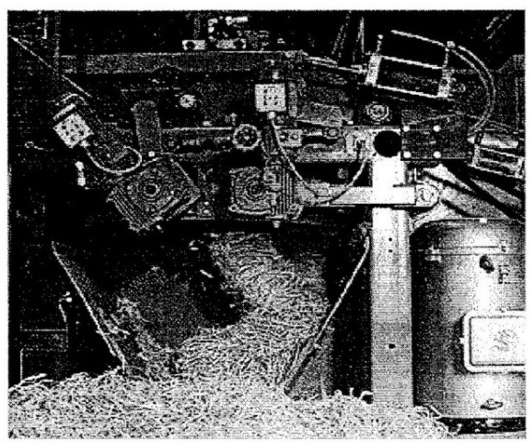

Figure 2: Shredding for wood wool

TANZANIA EXPERIENCE WITH WOOD CEMENT COMPOSITES

In Tanzania, the idea of using wood cement composites was introduced by a Polish settler in 1965 who brought to Tanzania a complete manufacturing plant and installed it at Meru Forest Project in Arusha. There was a full-scale production of wood wool/cement boards during his stay in the country but unfortunately, no production and consumption statistics are available since he left the country in 1970. (Kimaryo 1984).

OBJECTIVES OF THE INVESTIGATIONS

The objective of the investigation was to determine the optimum mix proportions of wood wool and cement to meet the minimum strength requirements as stipulated in the German Standard DIN 1101:1989 for wood-wool cement bonded composite boards for one common wood species, podocarpus spp and to investigate the influence of wood wool width size on the final strength of the boards. The German Standard was chosen because most previous studies on wood-wool cement bonded composite boards have been carried out using this standard. The wood species chosen for the study is very commonly found and widespread in Tanzania.

EXPERIMENTAL INVESTIGATIONS

Materials and methods

The botanical name of the species of wood used for the wood wool is podocarpus spp with a local trade name of podo. This is a softwood very commonly found in Tanzania growing at altitudes of about 2,500m above sea level.

The cement used was ordinary Portland cement (OPC) produced by the Wazo Hill cement factory in Dar es Salaam while calcium chloride($CaCl_2$) was used as cement setting accelerator.

The wood wool was obtained from wood shavings shredded to different width sizes of 4mm, 7mm, 10mm and 12 mm. The dimensions of the wood wool or excelsior were determined by using a digital caliper. Random sampling and measurement of 200 shavings showed that the shavings had an average thickness of 0.4mm and the lengths ranged between 50-400 mm.

Wood-wool cement boards (600mm x 1320 mm), 40 mm thick were produced using the different excelsior widths of 4mm, 7mm, 10mm and 12mm. For the investigation four wood: cement ratios (5:2, 3:2, 11:9, 1:1) were used. The percentages of water and accelerator were 50% and 3%, respectively based on cement weight. These percentages have been found optimum by Van Elten (1975). The board sizes were selected based on the test requirements of the German Standard DIN 1101:1989. Also a single board of such dimensions is of a practical size and weight that a single person can handle. The mixing ratios were selected based on a range of recommended ratios found during the literature review.

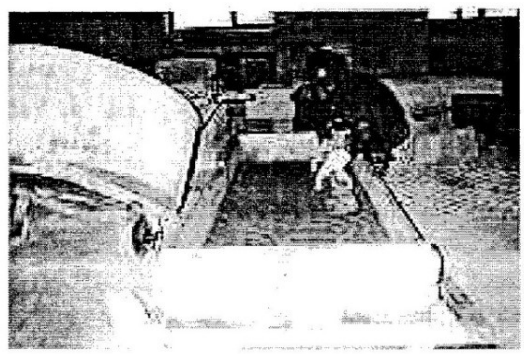

Figure 3: Filling mixed wood-wool into moulds

Figure 4: Wood wool in a mixer pan

The excelsior of each width was soaked separately in water for 24 hours to remove any inhibitory wood constituents like sugars. Water soaked excelsior was air dried in a shade for one day prior to mixing. Wood wool, cement and water containing the accelerator were mixed in a pan mixer (Figure 4) until all the wood wool was thoroughly coated with cement paste. The mixed wood-wool was then placed in a mould (Figure 3) covered with a polyvinyl sheet and subjected to a pressure of 5kPa for 24 hours. The pressure was then removed and the boards were cured for 28 days before being tested.

Property testing

Sixteen of the cured boards which measured 600mm x 1320mm were tested full size for flexural strength in a universal bending machine (MFL-BRP200). The load was uniformly applied across the board on an area measuring $40x600mm^2$. The rate of load application was $0.02N/mm^2$ /sec. A span of 660mm was used for all the tests.

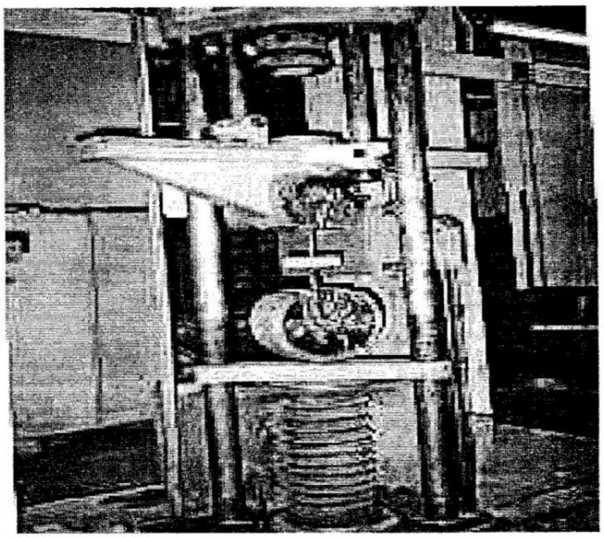

Figure 5: The Tensile test

Specimens measuring 200mm x 200mm were cut from the rest of the slabs and tested for compressive strength in a universal compression machine. The rate of loading was 5kN/minute. The maximum stress at 10% strain was determined in each case.

For the tensile strength test a special device had to be fabricated for the test. The reason for the fabrication was to avoid destruction of the specimen by the machine jaws during gripping. Specimens measuring 100mm x 100mm were cut from the boards and these were cemented between two steel plates of dimensions 10mm x 1000mm x 100mm by using epoxy resin. The steel plates had each a steel bar welded perpendicularly at the centre so that the tensile test could be done by clamping these bars in the testing machine. The tensile test was done perpendicular to the thickness of the specimens (Figure 5). The tensile load was applied at a rate of 0.02kN/sec.

Thickness swelling and water absorption properties were also measured after the specimens had been immersed in water for 24 hours.

All the above tests were done according to the requirements of the German Standard DIN 1101:1989.

RESULTS AND DISCUSSIONS

Modulus of Rapture

Figure 6 shows the average Modulus of Rapture (MOR) as a function of excelsior width and cement to wood wool ratio. As expected the MOR of the boards was affected by the cement: wood ratio. The maximum MOR occurred with boards with a cement: wood ratio of 3: 2. A similar result was observed by Eusebio et al (2000) but with Euclypts wood species.

The influence of width of the excelsior is also evident. Using smaller excelsior widths results into a higher MOR. The highest MOR were obtained with excelsior widths of 4mm. It appears that using excelsior with widths greater than 10mm results into a significant loss in the MOR. In this case there is a loss of about 70% at the optimum cement: wood ratio of 3: 2 The explanation for this is that the thinner the strands the bigger the bond area and therefore the higher the MOR.

Within the range of cement: wood ratios tested the values of MOR obtained far exceed the minimum requirement of $0.7N/mm^2$ specified in DIN 1101:1989. Again this is consistent with observations made by Sandermann (1970) who found that panels produced under prevailing local conditions are much better than those claimed by the standards. As mentioned before this standard was selected for these investigations because most previous researches on wood wool slabs have been based on the DIN 1101:1989 standard.

Compressive Strength

Figure 7 shows the variation in compressive strength with cement to wood wool ratio and wood wool width.

The standard DIN 1101:1989 specifies that compressive strengths of the WWC boards be evaluated at 10% strain and the values must exceed 0.2N/mm^2. From the results obtained it can be seen that all the tested boards passed this test. The compressive strengths of the boards increase with increase in cement content as expected since hardened cement paste like concrete is excellent in compression. The compressive strength, however, decrease with wood wool width presumably because the wider the excelsior the more voids you get in the mix for the same cement content due to the tendency of wider excelsior to curl.

Tensile Strength

Figure 8 shows the variation in tensile strength with cement to wood wool ratio and wood wool width. The standard DIN 1101:1989 specifies that tensile strengths of the boards should at least be 0.02N/mm^2. All the boards passed the tensile strength test. The optimum cement: wood-wool ratio was (as with the case of flexural strength) 3:2. Again the tests showed that using smaller wood-wool widths results into higher tensile strengths.

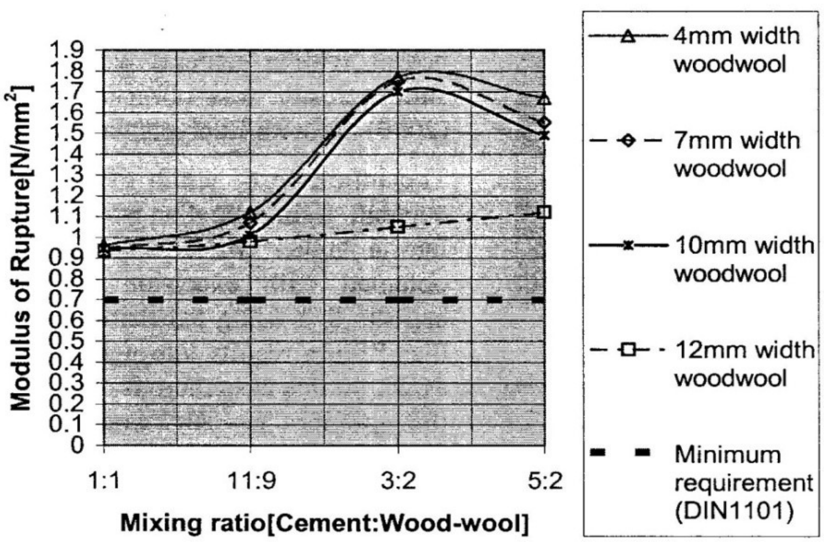

Figure 6: Variation of Modulus of Rapture (MOR) with cement: wood wool ratio and wood wool width.

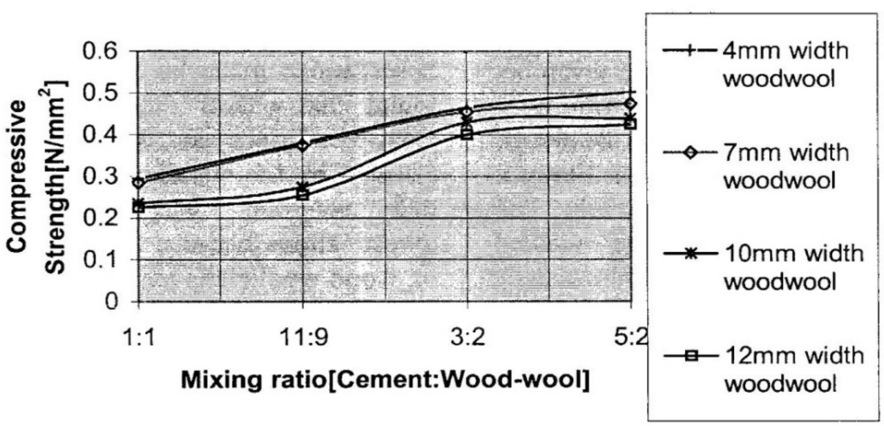

Figure 7: Variation of Compressive Strength with cement : wood wool ratio and wood wool width.

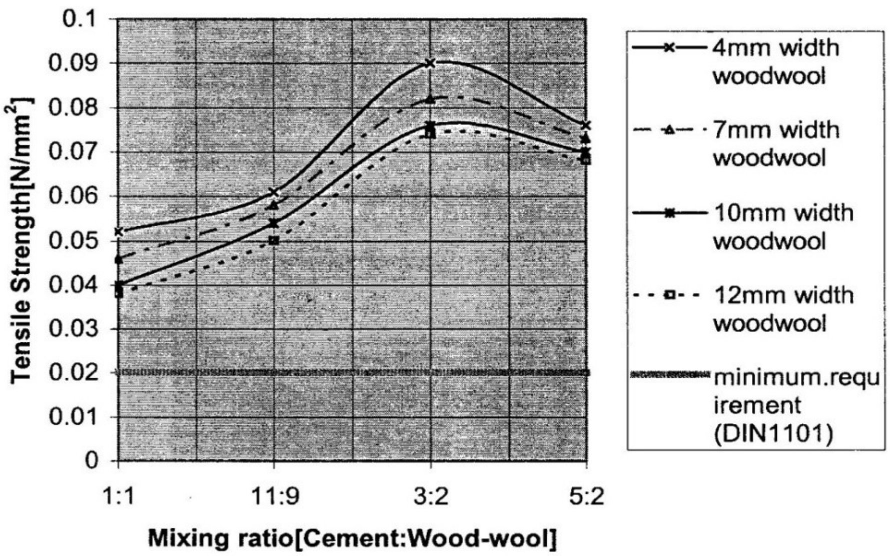

Figure 8: Variation of Tensile Strength with Cement: wood wool ratio and wood wool width.

Water Absorption and Swelling

Water absorption is related to the cement content. Higher cement contents lead to lower water absorption rates as expected because part of the cement paste fills the cavities. This is also true with swelling (Figure 9) Swelling is directly proportional to water absorption (Figure 10) regardless of the cement: wood-wool ratio. DIN 1101:1989 specifies a maximum thickness swelling value of 0.84% and a maximum water absorption value of 22%. The values obtained here were higher than the requirements of the standard. This can be corrected by applying a higher pressure to the WWC boards during manufacture.

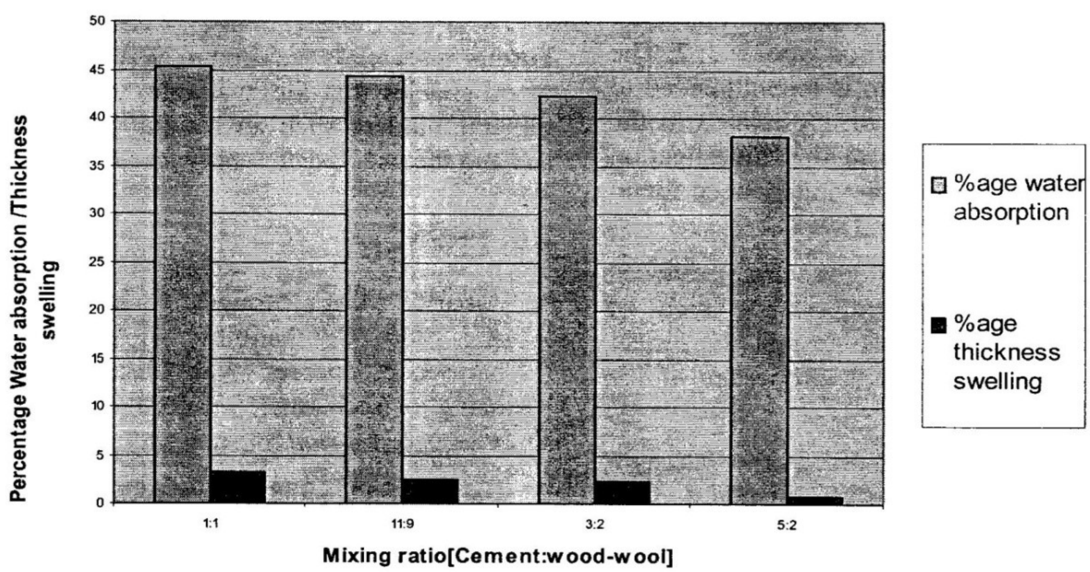

Figure 9: Percentage water absorption and thickness swelling against mixing ratio

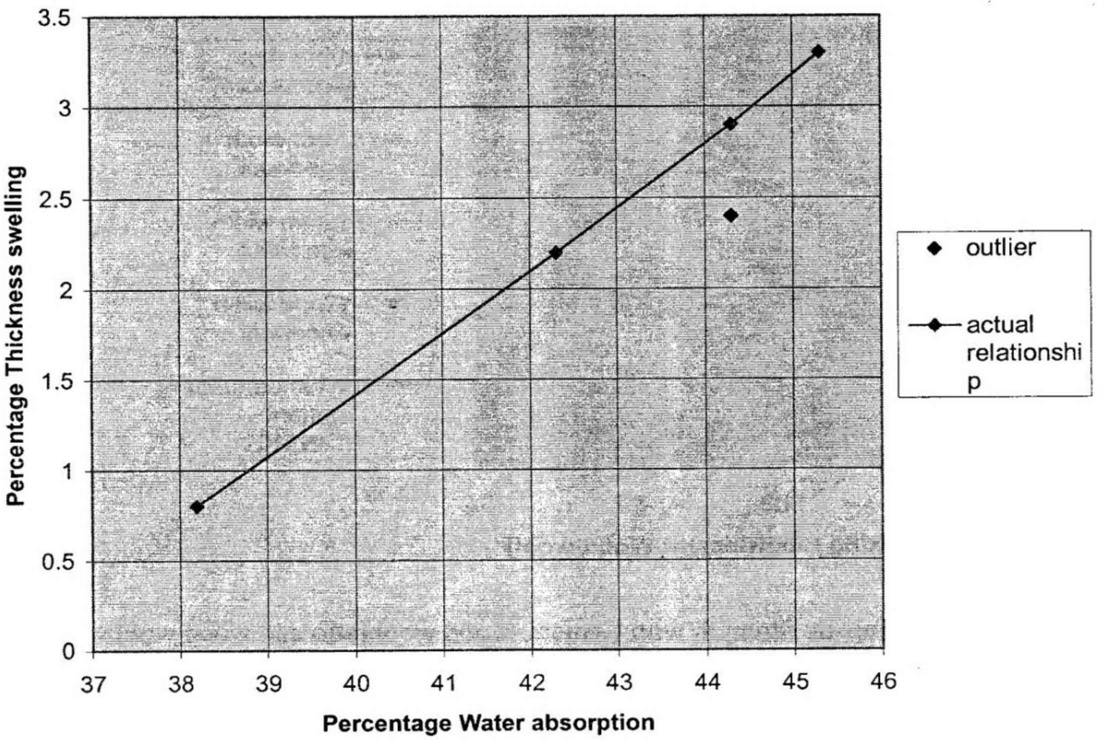

Figure 10: Relationship between percentage thickness swelling and percentage water absorption.

CONCLUSIONS AND RECOMMENDATIONS

For the species studied podocarpus spp the optimum mix proportion to make wood-wool cement boards is cement: wood wool = 3: 2. The optimum water cement ratio is recommended to be 0.5 and $CaCl_2$ content of 3% related to the weight of cement as used in this investigation because these ratios have previously been found to be optimum by Van Elten (1975).

Smaller wood wool widths are preferred because they increase the surface area of adhesion between the substrate and the binder leading to enhanced strength properties of the boards.

All the boards tested passed the strength requirements of the German Standard DIN 1101:1989. The boards, however, showed higher percentages of swelling and water absorption than those recommended in DIN 1101:1989. This can be overcome by adjusting the pressure applied to the boards during manufacture so as to reduce the amount of pores.

It is high time that investors and/or governments in developing countries consider this important alternative building material.

Further research is required to cover the different wood species that are available, using different mineral binders such as natural pozzolana, fly ash and the use of different types of accelerators.

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