

THE APPLICATION OF NATURAL FIBRE COMPOSITES IN CONSTRUCTION: A RESEARCH CASE STUDY

Llewellyn van Wyk

Built Environment Unit, Council for Scientific and Industrial Research, Meiring Naude
Road, Pretoria. Gauteng. 0001

lvwyk@csir.co.za

Abstract

Construction remains a significant consumer of raw materials, specifically non-renewable resources derived from the extractive industries. In addition, construction is a significant contributor to the emission of global warming gases, both through its dependence on the extractive industries, and its consumption of energy during and after construction.

Agenda 21 Chapter 4 addresses changing consumption and production patterns and Chapter 7(g) addresses sustainable construction activities. The strategies include interventions at policy and technology levels and it is the technology opportunity that generated CSIR's research into exploring natural fibre composites for construction products.

The objective of the research is to establish whether natural fibre composites (NFCs) could achieve the required performance levels of appropriate and relevant conventional construction materials. With regard to establishing the required mechanical properties the research identified four construction elements. These are load bearing elements, non-load bearing elements, solid section and hollow tube. The paper reviews the potential application of NFC in construction, identifies the prerequisite mechanical properties for equivalency, and prepares the targeted values for mechanical properties of NFC in construction.

The mechanical properties required were Young's Modulus, compressive strength, tensile strength, impact resistance Izod, flexural strength and shear strength.

The paper provides an overview of the procedures followed to establish the target values for the identified mechanical properties.

BACKGROUND

In a report dated March 2005 (PDP TH/2004/20) the use of agricultural crops (animal and plant), recycled materials and industrial wastes as a material source for developing construction products was investigated (van Wyk 2005). The report argued that a number of cogent reasons existed for undertaking such a review.

First, it noted that the building and construction sectors have an important contribution to make to the attainment of sustainable development. The construction sector is already a significant consumer of raw and natural materials and the current population increase of 73 million per annum will place higher demands on its consumption. In addition, the changing nature of society requires structures that are more flexible in use and deliver high performance immovable assets.

Second, the report noted that the use of agricultural crops would do much to remove the volatility and risk associated with the agricultural sector through the differentiation of new products and the diversification of non-food crops.

Third, the report noted that technological progress in the building and construction sectors is often the result of integrating and transferring breakthrough innovations from other industrial sectors, as opposed to innovations developed purely in, or specifically for, the sector. In addition, the report argued that the growing global-wide recruitment crisis experienced by the construction sector underscores the urgency to move the sector towards a 'high-tech' environment to attract high calibre recruits back into the universities and through into the industry.

The use of agricultural crops, industrial wastes and recycled materials for industrial manufacturing is far advanced in many countries with the European Union arguably the most advanced with regard to research into the application of non-food crops. In addition, the Council for Scientific and Industrial Research (CSIR) and the Agricultural Research Council (ARC) are currently engaged in the use of agricultural crops, for example, in the textile and automotive and aeronautical industries.

Fourth, the report considered a number of crop-based applications resulting from the specific characteristics of agricultural crops such as plant fibres, carbohydrates, proteins, oils and other speciality crops. These crops present opportunities for producing a wide range of construction products that can, in the main, exhibit improved performance characteristics over their non-crop competitors. The products cover, but are not limited to, insulation, light structural materials (based on straw, hemp, cotton, flax, sisal and sugar cane fibres), paints, floor coverings, geotextiles, thatch, biopolymers and bio composites including board products, and starches for packaging.

However, the report suggested that the most significant advance could be found in the newest – and the most exciting – market sector, namely matting-based products and composites. This sector, it is suggested, offers unique synergies with other related technologies such as computer-aided manufacturing, sensor technologies and technology that will assist the building and construction sector in delivering high performance immovable assets.

The report concluded that the use of agricultural crops offered the best opportunity for the building and construction sector as the use of industrial wastes and the recycling of materials was already under way in response to pressures arising from legislators, investors, and other stakeholders. A research framework was proposed that set out a pathway for progress and development for crop-based building and construction products that recognises the various barrier topics and the science-based interventions required to resolve them. A set of recommendations were also prepared that dealt with imperatives such as funding, basic and applied research requirements, product marketing, economics and sustainable development, consumer preferences, and education and training.

On the strength of the report, funding was obtained to test the suitability of fibre-based composite materials for manufacturing construction products. Three objectives were set for the research, namely:

- Determine whether fibre-based composite materials can satisfy key performance requirements of construction materials with regard to the National Building

Regulations and Building Standards Act (Act 103 of 1977), performance and mechanical properties exhibited by traditional construction materials and conventional composites, and the principles of ecologically sustainable development;

- Assess whether a range of construction components – namely load bearing, non-load bearing, hollow section, and an extruded solid section – can be achieved to satisfy market demands;
- Strengthen the competence of the CSIR in natural fibre composite technology; and
- Patent the fibre-based composite material.

Based on the target mechanical property values set, the CSIR polymer composite group prepared polyolefin's (polypropylene and high density polyethylene) and compatibilizer blends and polypropylene/flex fibre composites. A separate paper describing the experimental and testing procedures and results of various combinations of fibres, compatibilizers and matrices is submitted by the CSIR Composite Competency Area.

DRIVERS SUPPORTING THE APPLICATION OF NATURAL FIBRE COMPOSITES IN CONSTRUCTION

For purposes of this paper the construction sector is defined as:

“The Construction Sector comprises establishments primarily engaged in the construction of buildings and other structures, heavy construction (except buildings), additions, alterations, reconstruction, installation, and maintenance and repairs. Establishments engaged in demolition or wrecking of buildings and other structures, clearing of building sites, and sale of materials from demolished structures are also included. This sector also includes those establishments engaged in blasting, test drilling, land fill, levelling, earthmoving, excavating, land drainage, and other land preparations. The industries within this sector have been identified on the basis of their unique production processes. As with all industries, the production processes are distinguished by their use of specialised human resources and specialised physical capital. Construction activities are generally administered or managed at a relatively fixed place of business, but the actual construction work is performed at one or more different project sites” (CETA 2004:11).

The shifting of fringe technologies into mainstream technologies will not occur unless supported by key drivers. Fortunately, there are a number of drivers both globally and locally that positively influence the application of natural fibre composites (NFC) in manufacturing generally, and in construction specifically.

Sustainable development

The global pressures exerted on finite natural resources through modern¹ consumption and production patterns and the concomitant depletion of non-renewable resources occupy a central position in the developmental strategies of governments and non-governmental organisations. These strategies flow substantially from the Habitat

¹ The term 'modern' is used here to describe the period commencing with the Industrial Revolution.

Agenda and Agenda 21². Agenda 21, together with the Habitat Agenda, is also the South African Government's principal driver for sustainable development (Burger 2003/04:234).

Chapter 4 of Agenda 21 addresses the current unsustainable patterns of production and consumption and promotes the development of national policies and strategies to promote patterns of consumption and production that reduce environmental stress and meet the basic needs of humanity. The Chapter also urges research institutions to identify balanced patterns of consumption and production that the earth can support in the long term.

The construction sector is addressed in Chapter 7 of Agenda 21 which promotes sustainable construction industry activities and seeks the adoption of policies and technologies to enable the construction sector to meet human settlement goals while avoiding harmful side effects on human health and the biosphere. Among the identified activities are strengthening the indigenous building materials industry based on inputs of locally available natural resources and enhancing the utilisation of local materials by expanding the technology platform.

Buildings are significant consumers of raw materials: according to Edwards (2002) buildings consume:

- 50 per cent of all resources used globally
- 45 per cent of all energy generated through the heating, lighting and ventilating of buildings, and a further 5 per cent during construction
- 40 per cent of water used globally through sanitation and other uses in buildings
- 60 per cent of prime agricultural land lost to farming
- 70 per cent of global timber products

In addition, building activities and operations in the USA are responsible for 40 per cent of carbon dioxide emissions and 40 per cent of total wastes generated.

One of the central challenges facing the construction sector is selecting materials based on environmental performance (use of renewable materials, reducing the consumption of natural resources, and recycling). The bulk of current construction materials are derived from materials processed by the extractive industries (cement, steel, aluminium, sand, stone, clay and oil) and the manufacturing of many construction products therefore contributes directly to environmental damage and biodiversity loss (Mazria, 2006).

There is thus enormous potential for agricultural crops to reduce the environmental impact of the construction sector through the provision of a new generation of crop-based construction materials.

Modern methods of construction

Current construction methodologies have increasingly come under the scrutiny of construction stakeholders over the past sixty years: in the United Kingdom alone, at least 23 reports have been produced since 1944. More recently however, the

² The significance of Agenda 21 is to be found in its adoption by the United Nation's General Assembly as the fundamental 'Programme of Action' for achieving sustainable development.

construction sector in other countries have produced their own reports, including *Vision 2020* (2004) in Sweden, *Finnish Real Estate and Construction Cluster's Vision for 2010* (2001) and *The Construction Industry Technology Strategy* (2001) in Finland, *Construction 21* in Singapore (2002), *Construction 2020 – A Vision for Australia's Property and Construction Industry* (2004) in Australia, and most recently, the *Inventory of International Reforms in Building and Construction* (2004) in Netherlands.

A recent addition to this body of reports is the preparation of foresight studies for the sector. Unlike the reform initiatives that identify current failures with a view to introducing interventions aimed at correcting or minimising the failure, foresight studies aim to determine a number of future scenarios that can enable the sector to respond more effectively to future events. These reports include *Technology Foresight* report (1995), *Technology Foresight Ireland* (1998), *UK Construction 2010 – the Future Trends and Issues* (1999), *Adopting Foresight in Construction* (1999), and *Foresight: Constructing the Future* (2001).

Central to these studies is the recognition that the construction will need to become, and be perceived to be, a competitive state-of-the-art 21st century industry capable of producing efficient and sustainable infrastructure. New technologies, construction products made from renewable materials, intelligent elements, standardised, pre-assembled components and advanced materials will be required to deliver the high-performance buildings demanded by circumstances and customers (van Wyk, 2006). A shift toward a more manufactured-type approach to construction is generally anticipated. There is also an expected increase in the use of bio- and nanotechnologies in the future. Construction will need to track and optimise the benefits of advances in materials technology in building and construction activities in order to satisfy the demand for materials that offer improved performance overall.

In addition, Information and Communication Technology (ICT) is expected to be a powerful technological driving force providing customised and integrated information technology throughout the construction process.

Research, Development and Innovation in support of Economic Growth

There is an increasing interest in Europe and elsewhere in industrial biotechnology that specifically refers to bio-based environmental technologies. This interest is a consequence of the importance given to biotechnology and biomaterials as a key tool for delivering economic growth, competitiveness and sustainable industry development (OECD 2004:4). These areas of investigation are therefore likely to be major beneficiaries of European Union (EU) industrial policy and EU research expenditure in terms of the Framework Programme.

Much of the development of non-food uses of crops relies on scientific discovery both in plant science and industrial technology, and its translation to the market. The development of non-food crop uses in the construction sector will require research and innovation at every stage of the design and production process: RD&I will therefore constitute a central cross-cutting theme from which to build all of the strategic priorities identified in this paper.

The motivation for natural fibre composites for use in the construction sector therefore seeks to support the wider agenda for innovation and diversification in both agriculture and the construction sector to enhance South Africa's competitive performance while

contributing to sustainability imperatives in line with *South Africa's National R&D Strategy*. The CSIR is already engaged in agriculture and agro-processing through the development of technologies and knowledge in the cultivation and processing of essential oils, and through the expansion of the commercial farming sector, particularly within the emerging farmer category.

The innovation pillar of *South Africa's National Research and Development Strategy* (2002) involves the establishment and funding of a range of technology 'missions' that are critical to promote economic and social development. These include two key technology platforms, i.e. biotechnology and information technology (2002:44). Two additional missions are "technology for manufacturing" and "technology to leverage knowledge and technology from, and add value to, our natural resources sector" (2002:16). Bioscience applications in the manufacturing of crop-based construction products have an important role to play in areas such as the development of high value products combined with relatively low-value agricultural products that may be grown on a large scale.

There are clear synergies between the sectors identified by the department of Trade and Industry's (dti) *Advanced Manufacturing Technology Strategy* (AMTS) and the use of crop-based products in construction. The key technology focus areas of AMTS are:

- advanced materials;
- product technologies;
- production technologies;
- logistics;
- cleaner production technologies;
- ICT in manufacturing;
- small-and-medium enterprise development; and
- metrology.

To become a state-of-the-art industry and attract bright young recruits, the industry will have to underpin its efforts with an appropriate level of R&D.

Immovable asset performance

The construction sector is increasingly being called upon to deliver immovable assets that add value to the customers and society. A central theme of many global construction sector initiatives is improving the delivery and product performance of the sector. Developing new technologies consistently emerges as one of the strategies to be employed to enhance the construction sector and the value of its products.

In addition to the benefits of a production process based on the use of agricultural crops, there are also performance enhancements to be extracted from the use of crop-based products. In many instances, renewable and natural construction products yield improved product performance across a wide front, including thermal transmission values, moisture retention and resistance, allergic reactions, product stability and the ability to be recycled and reused. These benefits manifest across the whole life cycle of the product as well.

The development of a bio-composite technology platform for the construction sector holds all the promise of revolutionising construction in the same manner as iron and steel did in the 18th century.

Agricultural beneficiation

Agriculture forms a keystone in the economies in many countries: it is a significant employer of people (particularly the poor and the illiterate), makes a significant contribution to the growth of the economy and is critical to the retention of viable rural communities. However, agriculture is extremely vulnerable to externalities, including climate change, weather fluctuations, global competition, foreign exchange rates and unfair global trade practices.

Agriculture in South Africa is one of the main contributors to the increase in economic activity, and vice versa. South Africa has, however, an over-supply of nearly all field crops with the exception of wheat. This increases the risk to income security (low prices, strong Rand), with emerging farmers the most exposed. The low prices obtained due to these surpluses also impacts negatively on the farmer's ability to repay their loans.

Responses to these pressures are numerous, and the potential exploitation of non-food crops is one of the most recent. The Department of Agriculture (DoA) submits that this circumstance can only be overcome by establishing new markets, such as expanding exports (complicated by a fluctuating Rand), differentiating products, and entering the bio-diesel and ethanol markets. The introduction of non-food crops into the manufacturing of construction elements is an additional market for the agricultural sector that will enhance the economic viability of agribusiness in South Africa through added-value to existing and new crops.

THE USE OF NATURAL FIBRES IN CONSTRUCTION

There is considerable evidence that suggests that the potential exists for plant fibres to be used to produce a wide range of products which "can make a significant contribution to a more sustainable construction industry" (Holmes 2005:60). Plants can synthesise an immense range of compounds. As 'cell factories' they contain structures that can be used by the physical, chemical and biochemical sciences to produce useful materials such as fibres, starch, oils, solvents, dyes, resins, proteins, speciality chemicals and pharmaceuticals. Physical and chemical sciences can combine to produce new applications including fully bio-based composites such as boards in which the fibre component is made from hemp, flax or sisal and the resin binder from rape seed oil rather than the more commonly synthetic chemical resins.

The automotive industry has seen a steady growth in the use of natural fibre composites, largely attributed to:

- Comparative weight reduction of 10-30 per cent in comparable parts;
- Good mechanical and manufacturing properties;
- Scope for forming complex components in a single machine pass;
- Relatively good impact performance with high stability and minimal splintering;

- Occupational health and safety advantages in assembly and handling compared to, for example, glass fibre with its associated respiratory implications;
- Reuse of moulding off-cuts;
- No emissions of toxic fumes when subjected to heat;
- Good ecological credentials as a sustainable raw material resource;
- Superior environmental balance between material and energy use;
- Recycling possibilities by incineration with energy recovery or by regrinding; and
- Relative cost advantages compared with conventional constructions.

A review of the above characteristics confirms that many of the benefits enjoyed by the automotive industry could apply equally to the construction sector. What is of particular interest is the ability to mould complicated 3-dimensional shapes: this holds specific promise for future products in the construction sector.

Although the 2005 research project investigated the application of carbohydrates, proteins, oils and other non-food crops (van Wyk 2005:15), this paper focuses on the use of fibres in composites for construction purposes. A number of fibres can be found in plants, including bast fibres, leaf fibres, seed fibres, fruit fibres and wood fibres. Fibre crops are generally divided into two categories: long fibre crops and short fibre crops.

Long fibre crops include hemp and flax. Flax has been used traditionally to produce high value long fibre material for the textile industry. Hemp has a wide range of potential uses and has established market niches using fibre, pith, seeds and seed oils.

Short fibre crops include cereal straws, miscanthus grass, canary grass and short rotation coppice. Cereal straws are by-products of the cereal industry and have been used for some time by the board and paper industries.

There are however some critical performance requirements that determine the best application for crop-based construction materials. They are:

Economic performance – consideration in this category applies at a number of levels. i.e. low embodied energy in manufacture and in use, low water use in manufacture, low wastage in manufacture and in assembly, and the potential to recycle the product and the waste.

Social performance – consideration in this category involves the ability to overcome consumer resistance, provide high levels of health and safety during manufacture and in assembly, and facilitate the participation of small, medium and micro enterprises (SMEs), rural workers and women in the entire supply chain from collection and processing of raw materials to manufacturing and installation.

Environmental performance – critical in this category is the bio-degradability of the material at the end of its life-cycle, using materials with low toxicity levels and low emission levels, particularly of global warming gases (GHGs) in manufacture and in use.

Having regard for the above, the following generic construction products could be manufactured:

Roof coverings – this covers both roof tiles and roof sheets. Roof tiles are predominantly made from materials derived from the extractive industries, i.e. clay, cement and steel. Clay and cement tiles have the added disadvantage of weight resulting in higher design loads (dead weight) and installation load (live weight). Apart from this, these materials pose negative environmental impacts associated with high embodied energy, material waste and pollution resulting from the manufacturing process (air, land, and water).

Insulation – most insulation materials in current use are mineral fibre-based and pose significant health and safety risks during manufacture, installation and in use. Crop-based and natural fibre insulation have low negative environmental impact during manufacture, installation and in use; they offer high social impact in terms of growing, harvesting, processing and installation; they can outperform competing materials in use; and they are generally less toxic in manufacture, installation and in use. In addition, inorganic fire retardants can be added that inhibit flaming and smouldering combustion; and, in the event of a fire, crop-based materials are able to insulate the structure.

Wall and floor coverings – designers rely extensively on roof, wall and floor coverings to create the desired design character they seek. Accordingly, new and refurbishment and retrofit (R&R) contracts will consume considerable quantities of these products, and do so a number of times throughout the life cycle of the building. Invariably, R&R contracts discard as much of the wall and floor coverings as possible, resulting in significant waste and adding to landfill capacity burdening. Crop-based fibres have a long application tradition in construction with sisal, coir, cork, bamboo, linoleum, natural-fibre carpets and timber featuring prominently in interior finishes as high-value products. In addition they offer performance benefits in terms of toughness, thermal comfort, and indoor environmental quality.

Extruded sections – these sections are typically used for aluminium and/or steel door and window frames and decorative panels. In addition, extruded composite sections could replace timber typically used in roof construction and door and window applications. The substitution of fibre-based composites for timber holds significant advantages for the construction sector, including overcoming the acute shortage of acceptable-quality timber, and supporting carbon sequestration.

Boards – this extensive product range offers perhaps the most viable market for fibre-based composites. Boards are currently made from laminated timber sheets, compressed timber shavings and sawdust, particleboard and medium density wood fibres, and timber blocks. These boards are used externally (fascias, eave closures, panels, etc.) and internally (joinery, doors, panels, etc.) and come in a range of finishes (colour and texture). Fibre-based composites can also be used for ceiling tiles and sheets that are currently made from gypsum and paper. Certain products in the board range pose significant environmental and health risks, especially those containing volatile organic compounds (VOC). Crop-based fibre composites could be substituted in many of these applications. Two systems are already in use in the United Kingdom (UK): one makes use of compressed chopped straw in boards and is used for partitioning and roof coverings, the other is a particleboard made from bonding straw to resins. In the United States of America (USA) extensive use is made of Structural Insulated Panels (SIP) as both a load-bearing element and a cladding material. These boards are typically made from two layers of plywood laminated to an insulation core.

Fittings – the construction sector makes extensive use of a wide range of accessories (towel rails, door and window handles, catches, bathroom accessories, etc.). Materials normally used include aluminium, steel, brass, and various plastics (mainly oil-based). Most of these accessories could be made from fibre-based composites from the bio-plastics range.

DETERMINING THE MECHANICAL PROPERTIES

The determination of the required mechanical properties for a fibre-based composite that could be suitable for application in the construction sector is crucial to the acceptability of the product in terms of the legislation governing the erection of buildings in South Africa, namely the National Building Regulations and Building Standards Act (Act 103 of 1977) hereafter referred to as the NBR Act. The NBR Act sets out the standards under its Code of Practice SABS 0400-1990.

Given the list of products identified in Table 1, four applications can be extracted as generic to construction products namely:

- Load bearing element;
- Non-load bearing element;
- Solid section; and
- Hollow tube.

Comparability and equivalency

The required mechanical properties for a new construction material based on natural fibre reinforced composites can be established in comparison with equivalent conventional materials that are fit for the intended purpose. Given that the intention is to develop a new construction material that is at least equivalent to, if not better than, conventional construction materials, the equivalent reference materials must be selected for certain attributes. Since four applications or purposes are identified as indicated above, recognition must be given to comparable and equivalent materials for each of the listed applications.

Since the fibre reinforced composite is a flat panel, the mechanical properties chosen for comparative purposes must be equivalent: conventional construction technologies such as masonry walls are unsuitable since the strength of the wall depends, inter alia, on the strength of the mortar joints and the grading of the masonry element.

For purposes of establishing the desired mechanical properties the research assumed that the composite material panels will be manufactured in storey-height components in varying widths. It is further assumed that mechanisms will be developed which will enable the panels to be fixed to one another and that suitable anchorage for the foundations and the roof exist. Similarly suitable mechanisms might need to be developed to transfer loads around door and window openings. Thus the mechanical properties sought are those of the fibre-based composite alone.

Mechanical properties for structural element

A load bearing or a structural element, such as an external wall, has generally to fulfil several purposes. For instance, the wall of an ordinary house usually has to support the roof, keep the interior warm and dry, and provide protection from fire (for a specified

period) and noise. Where the wall is load bearing, its strength must be sufficient to carry the loads placed on it. These loads are calculated from the live and dead loads on the structure supported by the wall. Any building must be able to safely support the weight of its own components with an appropriate reserve of strength and stability. Wind pressure and impact forces must also be taken into account in the design of external walls, and indeed for panel walls in a framed structure the principal strength requirement is the power to withstand wind load.

All types of external walls must keep out rain. Weather exclusion may even be regarded as their most elementary and basic purpose, and, with very rare exceptions, it must be total. However, weather exclusion (where water is not expected to result in the degradation of structural capacity) and thermal insulation do not arise as criteria in the structural design of load bearing walls.

In addition, any building must be capable of resisting likely additional gravity loads and other forces that are likely to impinge on the walls and roof of the building – such as impact loads – with sufficient reserve of strength and stability.

Having regard for the NBR Act and the product application, the following mechanical properties require to be evaluated:

- Compressive strength
- Shear strength
- Impact resistance
- Young's modulus
- Tensile strength
- Flexural strength

In addition, safety issues surrounding fire resistance and stability will also need to be evaluated if the material is to comply with the NBR.

In the case of fibre reinforced composites the mechanical properties are derived from the properties of the fibre and the resin binder. In order to determine what constitutes acceptable mechanical properties for NFCs the properties of other composites likely to be used in a load bearing context need to be determined. Having regard for this, the scope of a comparable and equivalent material is limited to Oriented Structureboard (OSB) and Structural Insulated Panels (SIP).

Establishing a consistent set of mechanical properties for OSB is hampered by the differing standards in use. For example, some of the properties identified in the target values table below were not available from the European suppliers as they are not part of the common test and evaluation procedure for OSB panels in Europe. The data provided in Table 1 is as from the technical bulletins of the Structural Board Association (SBA) in Canada while the data in Table 2 is sourced from the European suppliers to PG Bison South Africa.

OSB and waferboard are generic structural board products: they are mainly engineered, mat-formed board products made of strands, flakes or wafers sliced from small diameter logs in the direction of the grain so that the inherent tree strength is maintained in the resulting panel. After slicing they are dried, blended with wax and waterproof exterior

type binders (generally phenolic resin), formed into a loose mat or pad containing three to five layers and pressed under high heat and pressure into a rigid, dense structural panel. Strands are usually up to 150mm long and 25mm wide.

Table 1: Oriented Strandboard and Waferboard Properties

Strength and Stiffness Properties	Oriented Strandboard (OSB)		Waferboard
	Grade 0-2	Grade 0-1	Grade R-1
Modulus of Rupture	12.4 MPa	9.6 MPa	17.2 MPa
Modulus of Elasticity	1500 MPa	1300 MPa	3100 MPa

Table 2: Eurostrand OSB/3Z

Eurostrand OSB/3Z	Young's Modulus N/mm	Compressive strength N/mm	Tensile strength N/mm	Shear strength N/mm
	4500 (length)			
	1800 (across)			
15mm thick		26.02 (length)	17.45 (length)	1.8 (length)
		20.68 (cross)	14.10 (cross)	1.96 (cross)
18mm thick		20.23 (length)	20.71 (length)	2.19 (length)
		19.68 (cross)	14.31 (cross)	2.23 (cross)

Structural Insulated Panels (SIP) consists of two outer skins, generally OSB with an inner core of expanded polystyrene. Alone these components are non-structural until they are pressure laminated together under quality-controlled conditions using a two-part latex construction adhesive.

Table 3: Structural Insulated Panels

Mechanical properties	Metric	Comments
Tensile strength, ultimate	0,8 MPa	Perpendicular
Modulus of Rupture	0.05 MPa	Static Bending
Flexural Modulus	7 GPa	Static Bending

Source: www.matweb.com/search/OSB

Manufactured fibres have been extensively used in composites for many years with glass fibre and asbestos fibre perhaps the most well known. While the use of asbestos fibres has been stopped due to environmental reasons, glass fibre is still extensively used. Among the more recently developed fibres are Kevlar and carbon. The mechanical properties of these non-bio based thermoset resins and fibre composites including but limited to polyester, epoxy, phenolic, polyurethane and melamine, are indicated in Table 4 below.

Table 4: Non Bio-based Composites

	Young's Modulus GPa	Compressive strength (Yield) MPa	Tensile strength (Yield) MPa	Flexural strength (Yield) MPa	Impact resistance Izod J/cm
Alkyd (polyester), moulded, glass filled	15	160	50	100	
Thermoset polyester, glass and mineral filled BMC	11-20	120-200	50-80	88-140	0.33-0.77
Phenolic, Novolac, mineral/fibre filled	9-11	165-235	40-60	72-86	0.15-0.29
Epoxy, moulded, glass fibre filled	10-30	180-310	100	80-700	0.21-24

Source: www.matweb.com/search/composites

TARGET VALUES

Having regard for the mechanical properties identified in the comparable tables above, target values that need to be met for the application of NFC in construction are as follows:

Table 6: NFC Target Values

Young's Modulus (GPa)	Compressive strength (Yield) MPa	Tensile strength (Yield) MPa	Flexural strength (MPa)	Shear strength (MPa)	Impact resistance Izod KJ/m ²
25	160-275	41-80	68-144	210	11-22

As the values for non-load bearing elements, solid sections and hollow tubes are substantially lower than that for load bearing composites, achieving the values of the latter will easily satisfy the mechanical requirements for the former.

CONCLUSION

For purposes of the research a number of assumptions have been made, most particularly with regard to the strength of the material. The assumption is that if the material succeeds in achieving the desired target strengths, other interventions are available for improving performance qualities such as thermal, acoustic and fire requirements. It is recognised that significant subsequent developmental work is required if the material achieves the target mechanical properties. Most critical of these will be flammability and methods of jointing, fixing and sealing. Only once a complete

building system has been developed can it be submitted for full NBR compliance assessment. Furthermore, it is recognised that the current method of NFC forming might not facilitate all the applications that are sought, in which case further research and experiment in this area will be required. The work reported in this paper however represents a critical starting point in the full exploitation of NFC in construction.

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