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DEVELOPMENT OF (INTERACTIVE) FACADE ELEMENTS ON BASE OF WASTE MATERIALS OF (WASTE) WATER COMPANIES

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Abstract

As the materials of a building are responsible for more than half of energy use of that building over the whole lifetime, low carbon materials are, in the framework of climate change, a necessity for future building. Within this framework a new material based on (bio-based) waste streams has been developed and demonstrated. The new material has a high bio circular content of >82%. It consists out of: waste fibers like toilet paper and roadside grass giving strength to the material; Calcium carbonate ($CaCO_3$), a waste material from drinking water companies, transporting all materials while compressing; Bio-based polyester resin, for 50% produced out of waste glycol of biodiesel production, made from animal waste and frying fat.

The material was demonstrated as façade elements in a very low-energy housing project participating in the Solar Decathlon Middle East 2018 challenge in Dubai. In addition a proof of concept of an interactive façade has been realised.

Keywords:

bio-based composites, circular economy, facade, material development

1 INTRODUCTION

Low carbon materials, built up out of local, bio-based materials have been used in construction for centuries. Since the industrial revolution, however, economic growth has become synonymous with the growth in the use of fossil fuels, worldwide material transport, running out of scarce earth materials, climate change and environmental pollution. To start reversing this trend, it is important to develop a circular, bio-based building economy.

Bio-based' means derived from biomass, a material of biological origin, excluding material embedded in geological formations and/or fossilized. Examples are paper and wood, but also plastics such as PLA whose building blocks are produced from sugars [Van den Oever 2017]. Biomass from plants, animals and micro-organisms can grow quickly. During growth the cyclical use of carbon is short because the CO_2 released during (after) use can be recaptured relatively fast. This in contrary to other, conventional, building materials like steel and plastic.

In the coming years the goal is to adapt almost all 7 million buildings in the Netherlands in order to comply with the Paris climate agreements. The Dutch homes are not sufficiently insulated and still use too much energy and have to be made energy efficient and self-sufficient. In addition, the Dutch government decided to use considerably less natural gas, because of earth quake problems in the northern part of the Netherlands, caused by the gas extraction. The government goal is to have a quarter of the homes free of natural gas by 2030. For this process too, it is important to reduce the energy demand and to insulate it in a far-reaching manner.

However, recent research by the renowned Royal Institution of Chartered Surveyors [Sturgis 2017] shows that more than 2/3 of all CO_2 is emitted during the building process and less than 1/3 during use to heat the building and the tap water. RICS has developed a very solid method to determine the total CO_2 emissions of buildings over a period of 60 years. This method is described in the 'Whole Life Carbon Assessment Building Guidance'. The CO_2 footprint of a building is divided into 4 groups. The largest amount of CO_2, more than 69%, appears to be in physical construction, maintenance and renovation. This CO_2emission is mainly caused by the production of materials and products, transport to and processing at the construction site.

In order to reduce this large share, we must use as much as possible low CO_2 emitting materials, which are produced locally. Such as cellulose, flax, hemp, mycelium, straw, lime hemp, metisse, reed, as insulating materials and wood and biocomposites as construction materials.

A consortium of companies and universities of applied science have developed a new, low carbon material based on bio-based waste streams. The material has been demonstrated as façade elements in a very low-energy housing project participating in the Solar Decathlon Middle East 2018 challenge in Dubai (see Fig 1).

Fig 1 Demonstration project VIRTUe team in Dubai

2 NABASCO 8010 MATERIAL

[Schmeh I 2008] researched the possibility to use natural fibers like hemp in a composites manufacturing process called Sheet Moulding Compound (SMC). The technical results then were promising, but up to now have not been followed by commercial success, due to the complex processing of natural ingredients into SMC sheets

A process, rather familiar with SMC is called BMC, Bulk Moulding Compound, or Dough Moulding Compound (DMC, see Fig. 2). In this process glass fibers, calcium carbonate filler and a polyester resin are being combined into a dough, which is being pressed under high pressure (10 MPa) and temperature 140ºC into a stiff and rigid, thermoset material.

The BMC process is amongst others used to produce the reflectors of headlights of cars, interior panels in trains and wash bassins. It covers 7% of the composite production in Europe [Witten 2013].

Working on bio-based composites, since 1998, NPSP took the initiative to adapt the relatively easy to process BMC material into a bio-based waste version. In collaboration with Nouryon (former AkzoNobel Chemicals) NPSP developed and patented the material.

The newly developed material consists out of:

- Waste fibers,: toilet paper, grass, reed and recycled textile giving strength to the materials;
- Calcium carbonate (CaCO3), a waste material from drinking water companies, transporting all materials evenly through the mould while compressing;
- Bio-based resin, for 50% produced out of waste glycol of biodiesel production, made from animal waste and frying fat;

2.1 Ingredients

. Next to fibers, fillers and resin a small amount of mould release agent and curing agent organic peroxide is used.

The fibers and filler are all locally produced waste streams. The resin is produced in Europe.

<u>Toilet paper</u>

Reuse of waste streams from waste water treatment plants (WWTPs) is increasing. The average inhabitant of Western Europe uses approximately 10 to 14 kg of toilet paper per year [European Tissue 2011]. The vast majority of used toilet paper is not recycled. KNN Cellulose produces cellulose base material (Recell®) out of the toilet paper waste streams, a tertiairy source.

<u>Grass</u>

Roadside grass clippings are high in fiber and mineral concentration, but are a problem fraction in the EU, because they are very heterogeneous and contaminated. It is a difficult waste stream to valuate from an economical or environmental point of view. The grass used has been supplied by partners in the Interreg funded Grassification project.

<u>Reed</u>

Common Reed is a grass species, and one of the most widely distributed vascular plant species in the world. Reed is a key species and plays a significant role in wetland ecosystems, it has the highest biomass and is abundant within wetlands. Burning of reed land (in winter) is common practice [Sluis 2013]. The reed was delivered by the Dutch State Forest Management: 'Staatsbosbeheer'.

<u>Recycled textiles</u>

The EU textile industry generates waste estimated at 16 million tons per year. Much of this waste is thrown in landfills or incinerated, with a high environmental impact and at great cost [Sandin 2018]. Valuable resources held within the waste are also lost. The recycled textile fibres used have been supplied by the Recurf-Up! consortium lead by the Amsterdam University of Applied Science (HvA).

<u>Calcium Carbonate</u>

Calcite is a carbonate mineral and the most stable polymorph of calcium carbonate ($CaCO_3$). Lime granules are released when softening drinking water. These are round, about a millimeter in diameter and consist largely of calcium carbonate. The color of the grains varies from location to location, from white to yellow / blond and from gray to brown. This color is usually caused by (trace) iron, organic matter and manganese. The grains are released in more than 50 production locations throughout the Netherlands and Flanders. The Calcite Factory milled and supplied the calcite in this project.

<u>Bio-based resin</u>

Like in the original BMC recipe, an unsaturated polyester molding resin is used. But instead of a conventional, crude oil based one, a partly (48%) bio-based variant has been chosen : the Enviroguard M 98054. This resin is derived from the waste glycol of biodiesel production.

2.2 Process

The viscosity of the BMC mixture dictates how effectively it can fill a mold. When at high viscosity, the pressure applied to the BMC is not enough for it to flow. When adding more resin to create lower viscosity, the mixture decomposes and the fibers remain in one place while the rest of the material flows without them. The optimization of the viscosity constrains the amount of each component that can be used when mixing BMC.

Having a large amount of fibers or longer fibers improves mechanical properties but makes the BMC more viscous. In the mixing process firstly the resin, additives and 60% of the filler are mixed thoroughly. In the second stage the rest of the filler and the fibers are added and the kneading can start.

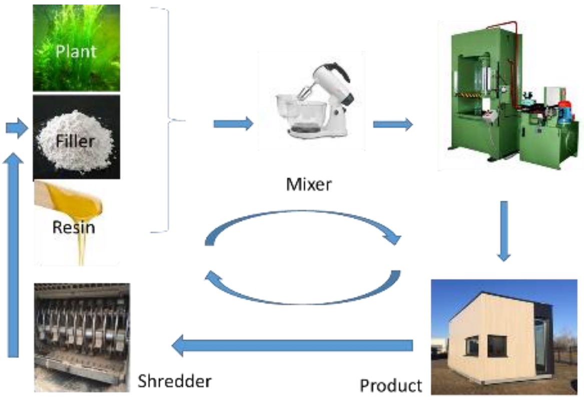

Fig 2 Circular production process of Nabasco 8010

The mixing and kneading of the ingredients is done in a IKA-Duplex HKD 10 kneader into the dough at room temperature. After ripening of the dough, usually one week, the dough is being pressed under high pressure (10 MPa) at 140 ºC in a steel mould (see Fig 3).

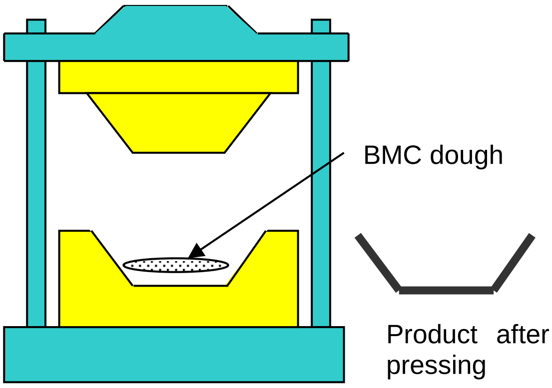

Fig 3 Schematic BMC moulding process

2.3 Mechanical properties

A 3- point bending test was performed according to standard ISO 178 (see Fig 4). The tensile test equipment was a Shimadzu AGS-X. According to ISO 178, the distance between the supported beams is 60 mm. The 3-point bending test was performed 5 times per specimen according to ISO178.

In table 1 the density and mechanical properties are shown. They are slightly lower than the conventional glass ones. But also the density is lower, so the intrinsical values are even closer.

2.4 Fire properties

The European fire classification of materials, construction products and building elements has been harmonised.

The base of CE-marking of construction products and building elements is the European system of fire testing and classification of products and elements. The reaction to fire classification of products is performed according to the Euroclass system.

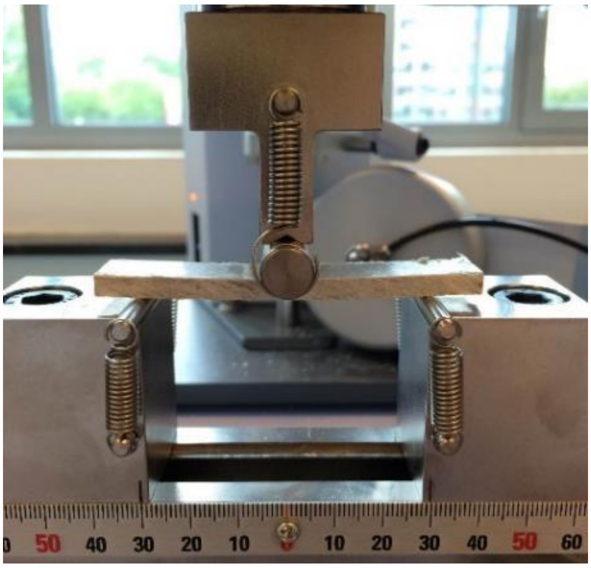

Fig 4 Set-up of 3-points bending test

To fulfil the highest possible fire standard for bio-based building materials, a special Reed Fire version has been developed, in which the calciumcarbonate has been replaced by Aluminium TriHydrate (ATH), resulting in a very fire resistant material. This was tested according to EN 13501-1. The material was qualified as, class B S1 d0.

3 DEMONSTRATION

3.1 VIRTUe

The VIRTUe-team of the building department of the Technical University Eindhoven (TUe) contacted the Nabasco consortium for production of a bio-based circular façade for their submission in the Solar decathlon. The Solar Decathlon Middle East 2018 has been organized by the Dubai Electricity and Water Authority and the government of Dubai in coalition with the US Department of Energy.

As the building is designed for the middle east, the façade needs to be light in color and have a special shape for an extra cooling effect.

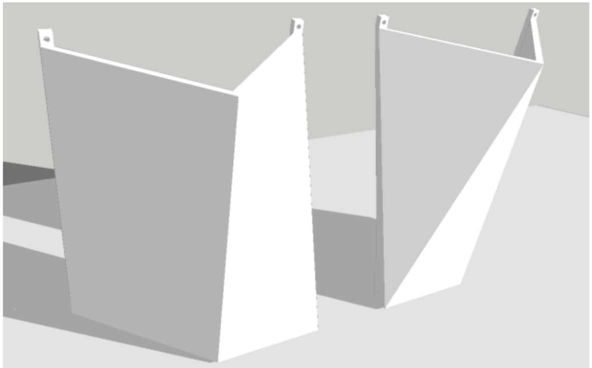

Fig 5 artist impression of left and right façade element

The façade elements were designed by the architecture and building physics students of the TUe.. The thermal cooling facade is a way to improve the natural ventilation of the building by using convection of sun-heated air. The air behind the panels becomes warm, rises and the draft ensures that cool air can be sucked behind again behind the panels (see Fig. 5)).

Titanium(IV)dioxide was added to the in chapter 2.1 described ingredients. The shape led to two defined moulds (left and right) that were developed to produce the facade elements.

Fig 6 Demonstrator with one source of fibers per element.

3.2 Interactive façade

Students of HZ University of Applied Science researched the possibilities to develop an adapting façade that responds to the environment using the Nabasco 8010 material [Rotier 2019]. The mechanism of the adapting façade was based on the biomechanics used in nature to protect animals and plants from changing weather conditions. Facades of buildings are static and do not alter in cold and hot weather, in contrast to skins of animals with their winter and summer coat,. This makes facades suboptimal in thermal insulation in winter or summer periods. An interactive façade could overcome this problem.

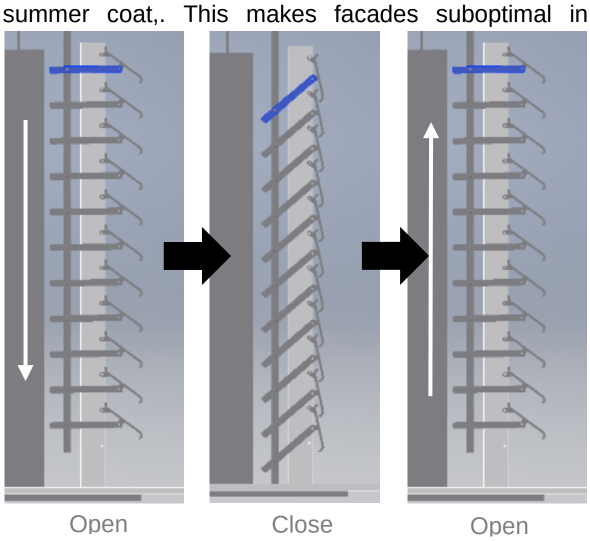

Fig 7 schematic working principle of interactive facade

A prototype was built and tested (see Fig. 7). The test setup contained a Arduino-powered façade element. The façade was moved by a servo construction. The inner temperature was measured by a BST-BME680 temperature sensor. To simulate a difference between temperature, a hair dryer was a representation of hot and cold air.

The façade opens above a temperature of 30°C. Opening the and applying 50°C air to the façade, results in opening the façade and remaining open at a temperature >-30°C.

To give a quick result for cooling down, the minimum temperature is set to 28°C. Opening the Arduino serial monitor and applying cold air, depending on the

environmental temperature, results in closing the façade at a temperature of -< 28°C.

4 LCA

Life cycle assessment (LCA) is a method for evaluating the environmental impact of a product, through making a list of related inputs and outputs for the product system, evaluating the potential environmental impacts of the product regarding those inputs and outputs, and interpreting the results of inventory analysis and impact assessment associated to the objectives of the research [Cao 2019].

The LCA case study was conducted according to ISO 14040 with the software CMLCA developed by the Faculty CML in Leiden University. The LCA was performed according the "cradle-to-gate" approach, including raw materials abstractions, production of semi-/products and transportations

The results of the fibers have been elaborated (see Fig. 8). The comparison was done considering the stiffness properties of a flat façade panel of 60 cm x 60 cm as determining property.

The results on the calcite and bio-based resin are still being researched.

5 SUMMARY

In a consortium of several companies and universities a new material has been developed out of waste materials. The new material has a high bio circular content of >82%. It consists of: waste fibers like toilet paper and roadside grass giving strength to the material; Calcium carbonate ($CaCO_3$), a waste material from drinking water companies, transporting all materials while compressing; Bio-based polyester resin, for 50% produced out of waste glycol of biodiesel production, made from animal waste and frying fat, consolidating the mix.

The material was demonstrated as façade elements in a very low-energy housing project participating in the Solar Decathlon Middle East 2018 challenge in Dubai. In addition a proof of concept of an interactive façade has been realized (see Fig. 1 and Fig. 9).

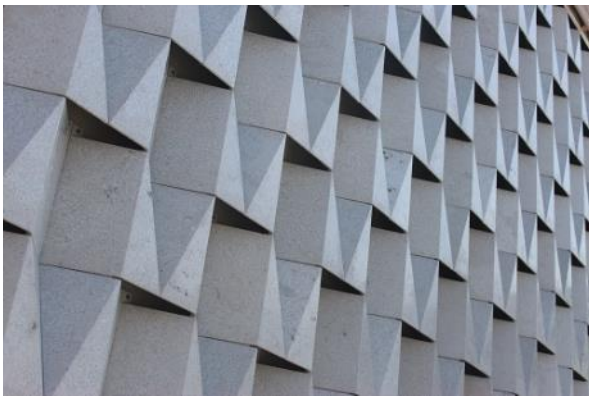

Fig 9 Façade view of VIRTUe demonstrator

6 ACKNOWLEDGMENTS

The project is a collaboration between the companies NPSP, AkzoNobel, KNN Cellulose and NewFoss. They were actively supported by the research group on bio-based building of the Center of Expertise Bio-based Economy and by the Virtue team of TU Eindhoven. Next to these the Spark Campus, Hogeschool van Amsterdam, Van de Bilt seeds and flax, water board Aa en Maas, Wetterskip Fryslân and Stowa and the University of Leiden supported.

Design of the façade has been done by the VIRTUE-team of Technical University Eindhoven, prototyping by students of TU Eindhoven, Avans and HZ University of Applied science, the material development by Nouryon, NPSP, Waternet, Aa en Maas and STOWA, the recycled roadside grass by NewFoss and Staatsbosbheer, Flax by Van de Bilt, recycled cellulose - Recell by KNN Cellulose and Wetterskip Fryslân, recycled reed and recycled calcite by Waternet, recycled textile by Amsterdam University of Applied Science, LCA conducted by NPSP under supervision of the University of Leiden. The project has been financed by Interreg North West Europe, Avans University of Applied Science, HZ University of Applied Science, NPSP, TU Eindhoven, AkzoNobel and Wetterskip Fryslân.

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Table 1 Mechanical properties by measuring 3-point bending strength and stiffness of flax, reed, textile, recell, grass and reed fire retardant,

		Flax	Reed	Textile	Recell	Grass	Reed Fire	Norm
Property	Unity							
Density	g/cm3	**1.7**	**1.8**	**1.9**	**1.9**	**1.9**	**1.9**	**ISO-1183**
3 point bending strength	Mpa	**35**	**35**	**39**	**40**	**39**	**30**	**ISO-178**
stnd.dev.	MPa	**4**	**4**	**2**	**2**	**2**	**1**	
3-point bending modulus	Gpa	**8.8**	**8.8**	**10.2**	**9.7**	**10.2**	**10**	**ISO-178**
stnd.dev.	GPa	**1.0**	**1.0**	**0.3**	**0.4**	**0.3**	**0.3**	

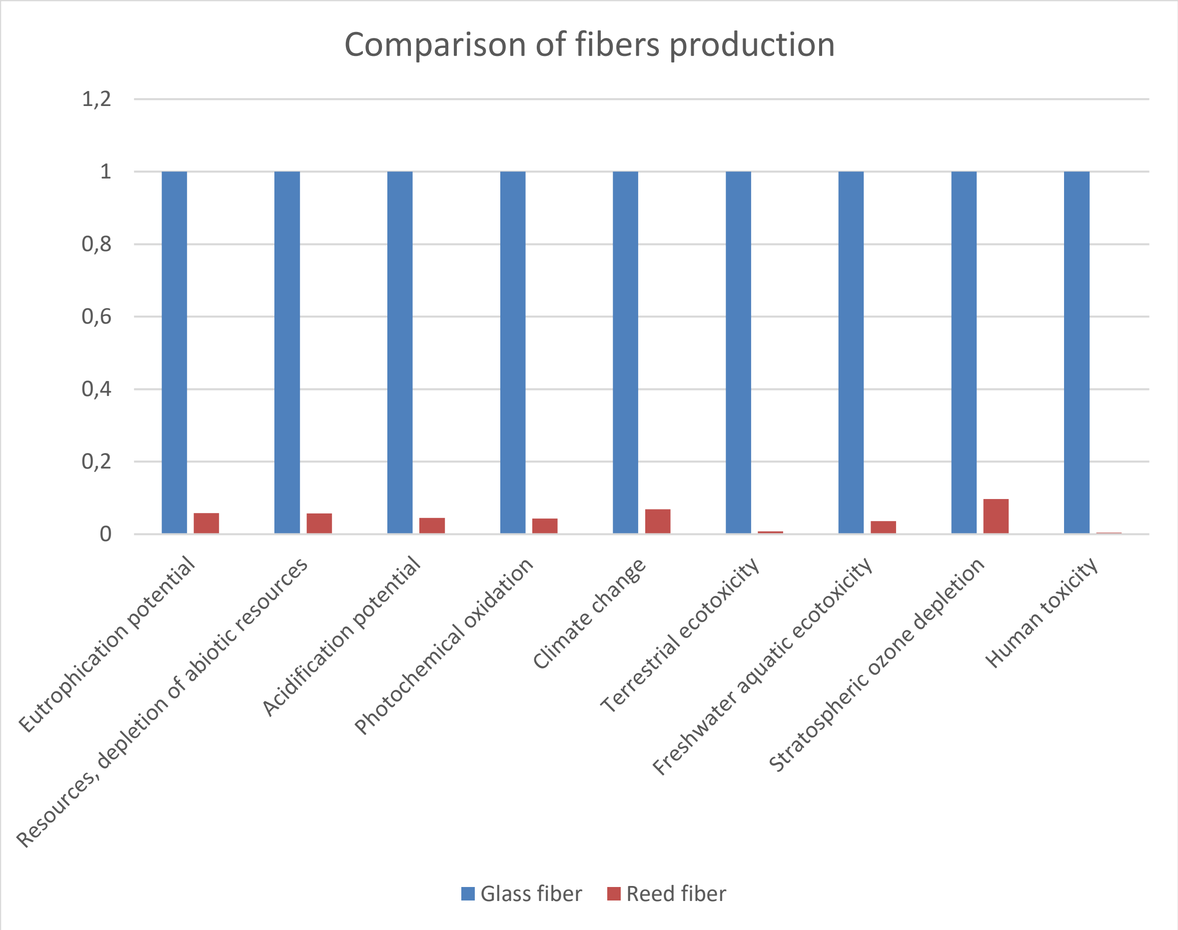

Fig 8 Normalized comparison of glass fiber versus reed fiber on 9 dimensions