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France (Channel Manche) England

BIO-CIRC Project

European Regional Development Fund

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Bio(and)**C**ircular **I**nsulation for **R**esourceful **C**onstruction

Prototype Concept Note

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Review and Input from Bio-Circ Partners

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Abstract of the project

The BIO-CIRC Project, Bio(and)Circular Insulation for Resourceful Construction, intends to tackle the building sector's high carbon, energy and resources dependencies while taking advantage of an unused waste resource: polyester from waste bedding.

The project aims to conceive, develop and deploy 3 prototypes of innovative low-carbon thermal insulation material made from polyester and combined with natural fibres. It intends to promote the emergence of a bespoke waste polyester valorisation industry and the use of virtuous Natural and Recycled Fibre Insulation products.

This project is carried out by a cross-channel partnership of 4 key and complementary links in the building sector's value chain:

- Nomadéis (lead partner)
- Alliance for Sustainable Building Products
- Eden Renewable Innovations
- Back to Earth

Planned over 2 years, the BIO-CIRC project receives funding from the European Regional Development Fund (ERDF). The ERDF's contribution amounts to €399,600 for a total budget of €499,500.

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Summary

Polyethylene terephthalate (PET) commonly known as polyester is the fourth most produces polymer in the world. Principal uses are synthetic fibres (60%) and packaging (30%). Polyester fibres are commonly used in filled bedding products such as duvets or pillows that generate significant waste at the end of life. Some PET based products such as post-consumer packaging are actively recycled whereas others such as filled bedding aren't.

Existing technology to enzymatically degrade PET into its constituent components (terephthalic acid and ethylene glycol) exists and is undergoing rapid development. This provides the prospect of dealing with the persistence of PET and provides useful end of life options for waste PET. However, much development is required. In the interim, it is therefore crucial to take plastic such as PET out of circulation until the technology to process the waste advances.

PET fibres are used to make safe, affordable and effective insulation. If PET fibres can be recovered and re-fiberized from PET fibre-based materials, these fibres can be converted into insulation. Duvets and pillows use Pet fibres designed to insulate so they are an ideal source for feedstock materials.

Whereas PET is hygroscopic, the degree of hygroscopicity and the natural of the moisture sorption isotherm is such that incorporating natural fibres into insulation containing rPET will impart breathable properties in the insulation. Sheep's wool and hemp are the most readily available and suitable fibres for this purpose.

This concept note described the physical and chemical properties of PET, recycling methods and impact of fiberizing on physical and chemical properties. The specification for insulation grade polyester is discussed. PET biodegradation technology is also discussed. Specifications for blends of PET and natural fibres are examined.

The aim of the work is to re-fiberize existing PET fibres rather than reprocessing PET and re-spinning new fibres. Three prototype specifications are detailed.

Rationale

In 2019 the UK government put into law its commitment to achieving net zero greenhouse gas emissions by 2050. This has further raised opportunities within sectors (including thermal insulation) related to delivering this ambitious goal.

All thermal insulation products reduce energy consumption and greenhouse gas emissions in service. There is now a need to double down on efforts to contribute even further. That means manufacturing insulation from materials that themselves have the least impact on greenhouse gas levels. Materials such as natural and recycled fibres is an established technology that holds the answer. But to date utilisation of these materials and technologies for insulation has been limited in the UK.

The entire UK insulation market is currently estimated to be worth £3-5bn per year at contractor's prices. The entire UK natural and recycled fibre insulation (NRFI) market is currently worth less than £20m annually representing a market penetration of less than 0.5%. Despite this, the market for NRFI is outpacing the general market and is currently growing at a rate in excess of 20%.

Barriers to growth include lack of awareness of the existing products, a lack of cohesion between existing technologies that could be utilised for insulation manufacture and a lack of more affordable raw material streams.

Currently NRFI is priced at the top end of the market range and sits alongside materials such as PIR and PUR. NRFI is approximately 50% more expensive that high quality mineral insulation and around 5 to 10 times the price of low-grade fibreglass insulation.

Raw material costs represent up to 75% of the cost of finished NRFI. As such finding lower cost raw material sources has the potential to dramatically reduce the cost of the finished product. A 50% reduction in raw material cost would result in a 40% reduction in the price of NRFI's. That would put the price point for NRFI at the level of good quality fibreglass and significantly open market potential.

Innovative solutions for new raw material streams require connections between existing by yet unconnected technologies. Technologies for sanitizing post-consumer waste pillows and duvets exists in the industrial laundry sector. The technology for converting pillows and duvets into reusable fibre exists for other home textiles at an industrial scale and there are numerous companies involved in the non-woven sector that have technology that can be used to turn these fibres into insulation.

The UK's leading supplier of polyester duvets currently manufactures 10m units per year. The polyester fibre in these duvets alone is enough to insulate around 200,000 properties per year if the fibre can be reprocessed.

By connecting the above technologies, it is possible to create a new industry from existing technology whilst significantly reducing the market price for the finished insulation products. Final market research during the project will enable us to complete the picture and more fully understand and promote the opportunity.

Polyester

Overview

Polyesters are semi crystalline polymers formed through the polymerisation of a dicarboxylic acid and a diol. Polyesters have an ester functional group in every repeat unit of their main chain. The most commonly used polyester is polyethylene terephthalate (PET).

The majority of the world's PET production is for synthetic fibres (in excess of 60%), with bottle production accounting for about 30% of global demand. In the context of textile applications, PET is referred to by its common name, polyester, whereas the acronym PET is generally used in relation to packaging. Polyester makes up about 18% of world polymer production and is the fourth-most-produced polymer.

PET consists of polymerized units of the monomer ethylene terephthalate and, with repeating ($C_{10}H_8O_4$) units.

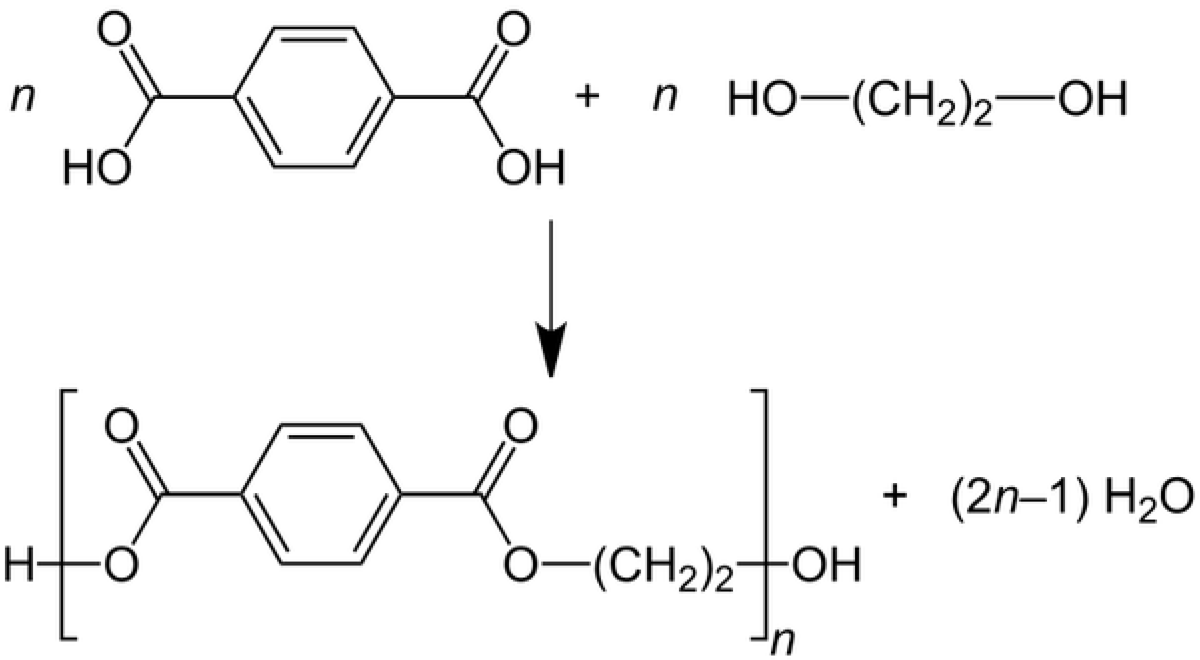


Table 1: Physical and Chemical Properties of PET

PROPERTY	VALUE
Repeating Unit Molecular Weight	192 $g.mol^{-1}$
Weight-average Molecular Weight	30,000- 80,000 $g.mol^{-1}$
Density	1.41 $g.m^{-3}$
Glass Transition Temperature	69-115 °C
Melting Point	265 °C
Heat of Fusion	166 $J.g^{-1}$
Breaking Strength	50 Mpa
Tensile Strength (Young's Modulus)	1700 Mpa
Water Absorption (24h)	0.5% w/w
Heat of Combustion	5.7 $Kcal.g^{-1}$
Limiting Oxygen Index	20.60%
Ignition Temperature	485-560 °C

End of Life

Recycling

PET is washed to separate dirt and water-soluble contaminants. PET is separated from other plastics and fibres using floatation separation and metals removed by electro-static and magnetic methods.

Recycling PET uses less energy than producing virgin PET. However, refiberizing PET fibres has the potential to use substantially less energy and would be the preferred end of life option for materials that contain PET textile fibres capable of being used in insulation.

Biodegradation

Microbial Polyethylene Terephthalate Hydrolases act on polyethylene terephthalate (PET) plastic. Enzymes which display PET hydrolysing activities include carboxylic ester hydrolase enzymes such as cutinases, lipases, and esterases (Guebitz and Cavaco-Paulo, 2008; Kawai et al., 2020). Hydrolases have been isolated from bacterial sources such as *Ideonella sakaiensis* and *Thermobifida fusca* and fungi such as *Fusarium solani*, *Humicola insolens*, and *Aspergillus oryzae* (Wang et al., 2008; Korpecka et al., 2010; Zimmermann and Billig, 2010).

Specifically, cutinases and cutinase-like enzymes are capable of processing high molecular weight polyesters (Taniguchi et al., 2019). Cutinases that have been shown to hydrolyse cutin, and various polyesters under temperature conditions of 40–70°C and pH 7–9, without the help of cofactors (Furukawa et al., 2019).

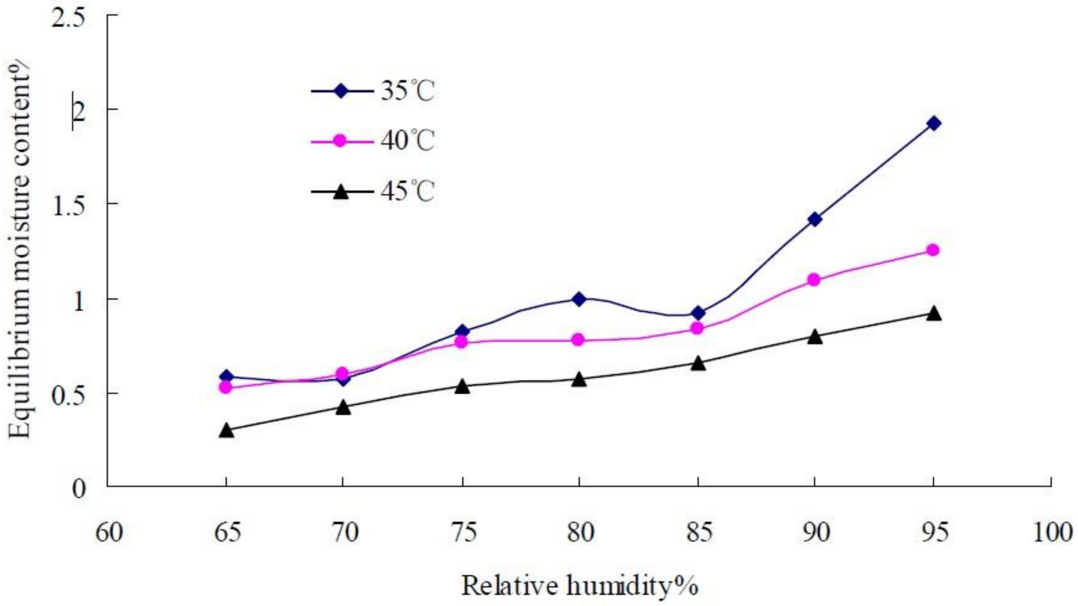
Genetic and protein engineering tools have commonly been used to increase the plastic degradation capacity of microorganisms and their enzymes, respectively (Wilkes and Aristilde, 2017; Jaiswal et al., 2020). The principal degradation products of PET hydrolysis are Mono-(2-hydroxyethyl) terephthalic acid (MHET), ethylene glycol (EG) and terephthalic acid (TPA). MHET can in turn be degraded by MHETase producing ethylene glycol and terephthalic acid. *Bacillus sp.* Have also been shown to further degrade TPA (T.B. Karegoudar, B.G. Pujar).

Table 2 – Selected PET active enzymes

Enzyme	Microbial Source	Reaction Temp (°C)	Substrate	Reported Degradation	Reference
BsEstB	*Bacillus subtilis 4P3-11*	40 - 45	3PET	TPA, MHET release	Ribitsch et al., 2011
Cut190	*Saccharomonosora iviris AHK190*	60 - 65	Amorphous PET film and packaging grade PET	TPA, MHET release	Kawai et al., 2014
IsPETase	*Ideonella sakaiensis 201-F6*	20 -45	IcPET and bottle-grade PET	TPA, MHET, EG release	Yoshida et al., 2016
PE-H	*Pseudomonas aestusnigri*	30	Amorphous PET film	MHET release	Bollinger et al., 2020

Hygroscopicity and Moisture Sorption

PET is slightly hygroscopic with a moisture absorption (24h) of approximately 0.5%w/w. PET is considered a hydrophobic non-breathable material. Research has been conducted whereby pores and surface grooves created in polyester fibres can create an element of moisture sorption and breathability (Hong-ru Liu 1,a*, Shang-ping Wu). The sorption isotherm below shows the moisture content of modified PET fibres under varying relative humidity and temperature.



Sorption isotherms show that surface modified PET is capable of moisture sorption at normal temperature, but this is limited to less than 1% which is an order of magnitude less than natural fibres such as wool or hemp. In order to impart a functional level of breathability into PET based insulation, it is necessary to incorporate natural fibres into the insulation.

Natural fibres

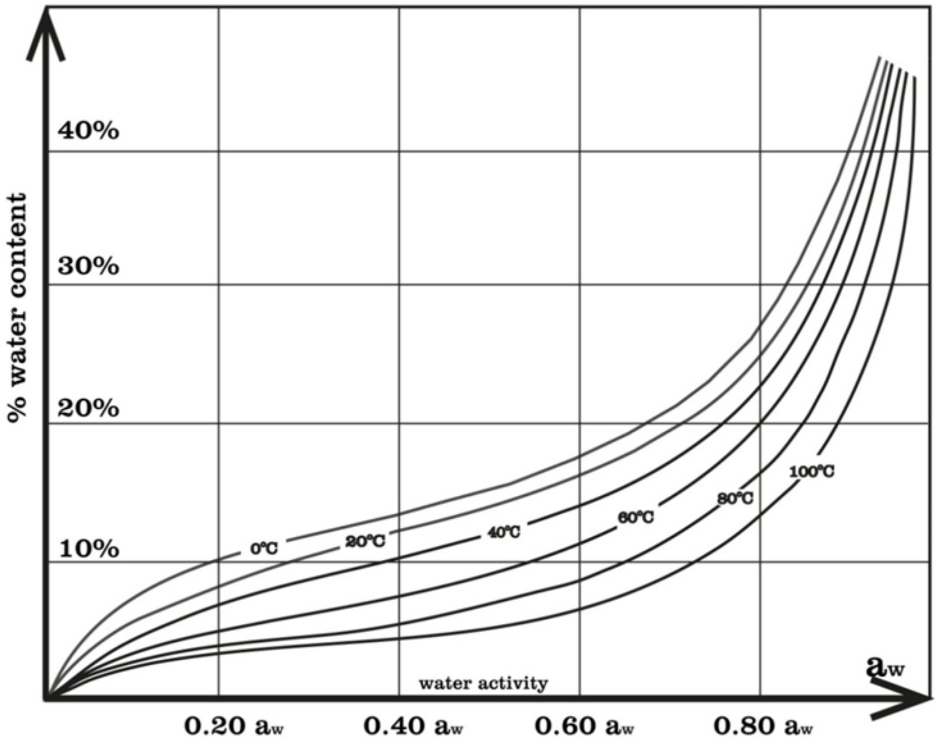
Natural fibre insulation has a number of principle properties that could be incorporated into a recycled polyester insulation if natural fibres were blended at the appropriate proportions.

Breathability

Heat and humidity are inextricably linked. It is well documented that sub-optimal moisture and humidity can have a very detrimental effect on occupants and the condition of the building fabric within dwellings. Poorly considered energy efficiency improvements can compound rather than solve problems associated with excessive damp and humidity. The UK Centre for Moisture in Buildings was founded to research, study and inform on these issues. https://ukcmb.org/

Breathability is an often over-looked or poorly understood aspect that can contribute to a healthy humidity balance within the home. Truly breathable materials work by allowing the passage of moisture where required whilst at the same time binding and releasing moisture in balance with internal humidity levels. This allows breathable materials to capture moisture and hold it in a safe form as well as preventing bottle necks that allow the build-up of moisture within the building fabric.

The moisture sorption isotherm below is typical of natural fibres and shows a functional moisture buffering capacity of approximately 10% of the natural fibre. This amounts to 100g per kg of natural fibre per sq.m of insulation used.



SI Sorption Isotherm

Thermal Buffering

Bio-based insulation and building materials have an optimal thermal mass that enables them to absorb heat at just the right rate to prevent excessive internal heat build-up during the hottest part of the day during warmer months. This helps reduce the demands from energy sapping air-conditioning systems during summer months and creates a vastly healthier temperature balance within the dwelling year-round.

Heat gain is measured by decrement delay. The level of decrement delay should form part of the performance measurements for new build and retrofit and recorded in EPC's for example.

Low Pollutant Source & Good Indoor Air Quality (IAQ)

Building materials can be a significant source of volatile organic compounds (VOC's). VOC's reduce indoor air quality and have the potential to cause harm. Controlling these pollutants at source should be a key consideration in the choice of materials and systems for retrofit. Excessive damp and humidity give rise to microbial VOC's (MVOC's) that contribute to a raft of respiratory and other diseases. Sustainable building products such as NFI's are a low source of VOC's and play a crucial role in maintain healthy indoor humidity levels helping control MVOC concentrations within the dwelling.

Insulation properties for hygrothermal modelling

Depending on the building material, certain hygrothermal properties are required to be quantified in order to determine expected performance of systems in which the material is incorporated. The table below outlines the requirements for WUFI relevant to the prototypes:

Material Property	**Standard**
Bulk Density	EN 1602
Porosity (%)	ISO 15901-1:2016
Thermal Conductivity	ISO 8301:1991 / BS EN 12667:2001
Water Vapor Diffusion Resistance Factor	EN ISO 12572 :2016
Water Absorption Coefficient	EN ISO 15148: 2002
Vapour Sorption	EN ISO 12571:2013

Prototype insulation specification

Materials

1. Polyester bi-component binder is required to hold the insulation fibres together. The minimum proportion of binder need to provide durability is 10%.
2. Recycled Polyester recovered from filled bedding waste and re-fiberized.
3. Coarse wool.
4. Technical Hemp.
5. Fire retardant – inorganic mineral.

Performance requirements

- ISO 8301:1991 Thermal Conductivity – minimum 0.044 W/mK thermal conductivity.
- EN 11925 - Fire performance –ignitability. Flame spread <150mm.
- ISO 12572 - Water Vapour Diffusion Resistance Factor – as determined
- EN 1602 – Bulk Density – as determined
- BS EN ISO 12571:2013 - Moisture Storage Function – as determined
- BS ISO 15901-1:2016 – Porosity – % as determined
- EN ISO 15148 - Liquid Transport Co-efficient – as determined

Structure

- Thermally bonded quilted insulation
- Thickness >50mm
- Width 300-600mm
- Length 1200mm
- Density – sufficient to achieve minimum 0.044 W/mK thermal conductivity.

Composition and estimates of raw material needed

It is anticipated that in order to run a new production factory, 500 tons of rPET reclaimed from bedding waste per year should be sufficient. Calculations can be made to estimate the quantity of other raw material needed. Prototypes' compositions and associated quantities are presented in the table below.

		rcPET recycled from duvets/pillows	rPET recycled from PET bottles	Sheep's wool	PET cobinder
Prototype 1	*%*	65%	25%	0%	10%
	Quantity (t)	500,0	192,3	0,0	76,9
Prototype 2	*%*	25%	0	65%	10%
	Quantity (t)	500,0	0,0	1300,0	200,0
Prototype 3	*%*	39%	0	51%	10%
	Quantity (t)	500,0	0,0	653,8	128,2

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