FIBCEM – FINAL REPORT

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1. Final Publishable Summary Report

Executive Summary

This report summarises the work conducted by the project consortium during the 36 month period of the FIBCEM project (1st December 2011 to 30th November 2014).

FIBCEM is funded under the Seventh Framework Programme (FP7) for EU research and is entitled "Nanotechnology Enhanced Extruded Fibre Reinforced Foam Cement based Environmentally Friendly Sandwich Material for Building Applications".

The overall aim of the FIBCEM project was to develop a cement based, nanotechnology enhanced, sandwich material that could be produced by a low energy extrusion process. The end application for the developed sandwich material was targeted at roof tiles and external building claddings.

The FIBCEM project has achieved almost all the scientific and technical objectives that were defined for the project with relatively minor deviations, however during the integration phase, co-extrusion of core and skin proved to be very challenging due to the different rheology between the skin and the core and problems with the dispersion of the fibres in the skin.

Due to these difficulties the consortium formulated an alternative plan in the final 9 months of the project to be able to achieve a FIBCEM material and process with potential to be developed into a commercially marketable product. The alternative plan was based on the development of a single extrusion process for a single composite material that combined the properties of the skin and the core.

The developed FIBCEM composite material is a low density material with reduced CO2 emissions, similar acoustic properties, thermal properties and fire proof capability compared to existing FRC based products. The material does not have the high strength and low permeability skin which was intended to resist the harsh conditions of the intended environment for the product, however the material could be exploited within internal building applications.

The developed product can offer significant benefits over existing FRC based products due to the reduction in the CO2 footprint caused by the reduction in the amount of cement in the material and the low energy extrusion manufacturing process. The developed material can also offer better environmental results in all impact categories compared to equivalent commercial products.

The modelling of a low energy screw extrusion process has been successfully developed and used to optimise the extruder design to achieve an optimal balance of throughput against energy consumption. This included the development of an elasto-viscoplastic model for modelling cement based materials and an analytical model for simulation of the screw extrusion.

Models of the cement sandwich materials have been developed for the core, the skin and the skin/core/skin sandwich. The impact of the fibre content and orientation in the skin and the impact of voids in the core have been studied to enable optimization of the material. Analysis of the FIBCEM sandwich material has been performed with focus on layer thickness and layer material properties with the required properties of hardened skin & core materials determined to meet the overall targets for the sandwich material.

Methods for surface treating nanoclays for enhanced compatibility and dispersion with cement based materials has been performed to optimize nanoclay particle bonding to enhance the mechanical transport properties of the FIBCEM materials. A range of surfactants were identified and evaluated; one was shown to achieve excellent particle dispersion of modified nanoclay without the need of antifoam and another achieved good particle dispersion but required antifoam.

The Chemistry and physical properties of candidate materials for foaming agents and effects of potential foaming gases on cement chemistry have been investigated. From this study it was shown that the recommended dispersants are surface active materials and may influence hydration of cement with further study needed. The study also identified that Silica fume & nanosilica are useful for property enhancement.

The application of Superabsorbant polymers (SAP) to create nano and micro-voids by water absorption has been investigated, optimized and selected for use in the FIBCEM material. The study concluded that SAP works well for controlled cell porosity generation and that SAP addition promotes cement hydration.

Nanoscale foaming agents, that do not create greenhouse gases, required to form a cement foam suitable for dispersion in cement based materials have been evaluated and screened for use in the FIBCEM core material. SAP, extendospheres (EXT), fine aggregate particles, lightweight aggregate particles and expanded polystyrene spheres were screened together with Chemical foaming agents (CFA). The analysis showed that EXT gave the optimal mechanical performance, CFA was best on price; however SAP was shown to give optimal price/cost performance and was selected as the most suitable foaming agent for the FIBCEM core.

The creation of surface modified nanoclays compatible with fibre reinforcement cement and cement foams enabling uniform dispersions of nanoclays has been achieved. The modifying process was scaled up from laboratory to plant and a product based on this process is now being industrially produced by Laviosa. Surfactant foaming agents (SFA's) were selected for use in the foamed cement with recommendations on the ratio of SFAs to organoclay made to account for the adsorption of nanclay particles.

Polymeric modular screws were successfully developed and implemented to save 30% energy. They were used to extrude the core and skin materials at room temperature with no distortion of screws detected and the wear characteristics were very similar to that of the wear characteristics of the metal screws.

An aluminium co-extrusion die has been developed for co-extrusion of cement foam core and FRC based skin. Manufacturing trials of the developed system showed that the skin & core materials were well extruded separately using the core extrusion die and samples produced using this method, were used for some of the performance testing. Co-extrusion of core and skin proved to be very challenging due to the different rheology between the skin and the core and problems with the dispersion of the fibres in the skin. This caused significant problems in the extrusion of the skin material with a thickness of 2mm while reinforced by 4mm-long discrete fibres.

The project consortium evaluated countermeasures to produce co-extruded material, but concluded that to achieve a FIBCEM material that could lead to a commercially marketable product, an alternative material would need to be developed. An alternative plan was formulated which was based on the development of a single extrusion process for a single composite material that combined the properties of the skin and the core. The outcome of this alternative plan was the development of a process using a formulation defined as “Mix 4B”

The final summarised test results and described potential impacts are based on using the single composite material using the formulation defined as “Mix 4B” that used a combination of the core and skin materials. The tested samples described in this summary were made using the Mix 4B formulation but were processed by either a cast/compress, cast/rolled or single extrusion process.

This single composite material is referred to as “FIBCEM Plan B”

The developed skin/core/skin sandwich structure is referred to as “FIBCEM Sandwich”

Summary Description of Project Context and Objectives

FIBCEM's principle objective was to develop a novel high-performance closed-cell foamed fibre-reinforced cement (FRC) sandwich material to be used for the commercial production of various geometries, in particular roofing tile and sidings. The sandwich structure was to comprise a lightweight cement foam-based core and a nanoclay and short discrete polymer fibre-reinforced cement skin. The developed material was targeted with having a short setting time and produced using an extrusion-based process during the same operation. The material was targeted with providing a number of benefits over the current state-of-the-art such as:

- Significantly reduced use of cement (*lowering CO_2 footprint*);
- Improved *specific* mechanical properties
- Lower density and, consequently, lower mass products (*reduced transportation and installation time and costs*)
- Improved functional properties (such as increased thermal insulation and acoustic insulation)

In order to achieve its objectives the FIBCEM project has a number of Scientific and technical innovations to be achieved over the project period.

The specific scientific objectives are centred on the development of new knowledge in the field of cement foams and foaming agents, the nano-scale reinforcement of cement and cement extrusion:

- Modelling of low energy extrusion of the FIBCEM material
- Modelling of cement sandwich materials properties to determine optimisation strategies for overall material properties
- Methods for surface treating of nanoclays for enhanced compatibility and dispersion with cement based materials
- Chemistry and physical properties of candidate materials for foaming agents and effects of potential foaming gases on cement chemistry
- The investigation and application of Superabsorbant polymers (SAP) as a novel method to create of nano and micro-voids by water absorption.

The detailed technical objectives are as follows:

- Development of two alternative nanoscale foaming agents
- Development of foaming agents which do not create green-house gases to form a cement foam suitable for dispersion in cement based materials
- The creation of surface modified nanoclays compatible with fibre reinforcement cement and cement foams enabling uniform dispersions for up to 10 Vf% of nanoclays
- Development and Implementation of polymer-based modular extrusion screw to save 30% energy
- Extrusion die development for co-extrusion of FRC

- Material composition optimized for low energy extrusion of FRC skin material containing up to 10V_f% of polymer and 10V_f% nanaoclay

The detailed integration performance objectives to be achieved are:

- Low energy consuming extrusion process for novel cement sandwich material capable of producing sheet material with thickness of 2 mm to 25 mm
- A sandwich material with the following improvements in properties compared to reference CEMBRIT FRC based product

- Density:	Decrease 10 to 50%
- Flexural strength:	Increased by 20%
- Shear strength	Increased by 20%;
- Flexural elastic modulus	Increased by 20%
- Charpy Impact Strength	Increased by 30%
- Thermal conductivity	Decreased by at least 20%
- Water absorption (wet over dry)	Reduced by 30%
- Fire Rating	A1

- A reduction of up to 50% in the amount of cement used compared to equivalent conventional FRC
- A total production cost for the material in the form of roofing tiles and siding no more than 5% greater than current equivalent material.
- 'Cradle to grave' Life Cycle Analysis of the material and extrusion process using the International Reference Life Cycle Data System (ILCD) created by the European Platform on Life Cycle Assessment.

The R&D activities were implemented within 10 defined work packages. These being:

Research into the individual components that make up the FIBCEM material

- WP1 - Base material composition (M1 ~ 12)
- WP 2 - Modelling of cement extrusion (M6 ~ 30)
- WP 3 - Investigation of foaming systems (M2 ~ 18)
- WP 4 - Nanoclay modification (M1 ~ 18)
- WP 5 - Modelling of FIBCEM material (M6 ~ 25)

Development of the FIBCEM materials and Extrusion process

- WP 6 - Extrusion process development (M1 ~ 26)
- WP 7 - Cement foam development (M8 ~ 26)
- WP 8 - FRC 'Skin' development (M8 ~ 29)

Integration and testing of the FIBCEM material

- WP 9 - Integration of technical developments (M22 ~ 31)
- WP 10 - Testing of FIBCEM material (M29 ~ 36)

Description of Main S&T results/foregrounds

The results achieved against the scientific objectives of the project are as follows:

Modelling of low energy extrusion of cement-based material

- Various test methods & data interpretation theory established for characterisation coupled elastic, viscous and plastic (rheological) properties of semi-solid, dough-like fresh cement based paste-like materials tailored for extrusion
- An elasto-viscoplastic (E-VP) computational constitutive model has been established for such semi-solid, dough-like fresh cement-based materials for extrusion & the model has been validated by axisymmetrical processing including ram extrusion and upsetting
- An analytical (numerical) model has been built for simulation of screw extrusion with high flexibility for further development and high transformability & the model has been self-validated
- Screw extrusion process for fresh cement-based materials has been optimised with the balance of product rate and energy consumption with respect to screw pitch, screw angle and die-exist aspect ratio

Modelling of cement sandwich materials properties to determine optimisation strategies for overall material properties

- A micromechanical strategy to predict the mechanical and thermal fields of the core and skin of the FIBCEM has been defined as result of the properties of its constituents and microstructure
- This strategy is the baseline of simulation of skin and core materials where the effect of some variables of the composite are analyzed and its results are applied to the macroscale modelling of the FIBCEM sandwich material
- Sensitivity analysis of skin material shows that the most influential parameters are fibre content and fibre orientation in tensile response & the effect of fibre in effective thermal conductivity is low
- Sensitivity analysis of core material indicates that the most influential parameters is voids volume with size distribution much less significant; dispersion of voids has higher impact in tensile behaviour than size distribution; tensile strength of cement paste matrix has an important effect in the effective compression strength
- Sensitivity analysis of FIBCEM sandwich material has been performed with focus on layer thickness and layer material properties at mechanical, thermal & combined mechanical/thermal fields with the required properties of hardened skin & core materials determined to meet the targets for sandwich material
- A numerical tool for predicting mechanical/thermal behavior of sandwich cement-based materials has been built.

Methods for surface treating nanoclays for enhanced compatibility and dispersion with cement based materials

- A range of surfactants have been identified and evaluated for dispersion of organically and inorganically modified nanoclay.
- Synperonic 10/6 and Zephrym 3300B surfactants have been selected as the most appropriate for dispersion and used in cement formulation.
- Zephrym 3300B is able to achieve excellent particle dispersion of modified nanoclay without the need of antifoam.
- Synperonic 10/6 is able to achieve good particle dispersion of modified nanoclay but requries antifoam.
- Both surfactants provide stability at high pH/electrolyte.

The Chemistry and physical properties of candidate materials for foaming agents and effects of potential foaming gases on cement chemistry

- Material properties including transport properties of CFA foamed cement based materials have been studied. CFA usually reduce mechanical strength of cement.
- **SAP** on the other hand has been found **beneficial to cement hydration** therefore enhance mechanical strength of cement based materials.
- Pozzolanity of **nanoclay** enables the additional consumption of $Ca(OH)_2$ therefore producing **additional C-S-H hydrate**.
- The recommended dispersants are surface active materials and may influence hydration of cement with further study needed.
- Others: Silica fume & nanosilica are useful for property enhancement (strength, rheology).

The investigation and application of Superabsorbant polymers (SAP) as a novel method to create of nano and micro-voids by water absorption

- Laboratory scale batches of cement mixture containing SAP have been prepared with samples produced.
- Strength, density, pore size, rheology and extrudability of SAP foamed cement mixtures have been tested at hardened / fresh states.
- Environmental impact_of SAP as cement foaming agent has been studied with comparison made with other foaming agents. Usage of SAP as foaming agent has been optimised and selected for the project.
- Porosity of SAP foamed cement_has been measured by CT with conclusion that SAP works well for controlled cell porosity generation.
- TG analysis indicates SAP addition promotes cement hydration.

The results achieved against the technical objectives of the project are:

Development of two alternative nanoscale foaming agents - Chemical Foaming Agents (CFA) and Super absorbent Polymers (SAP), which do not create green-house gases to form a cement foam suitable for dispersion in cement based materials

- SAP, extendospheres (EXT), fine aggregate particles, lightweight aggregate particles, & expanded polystyrene spheres have been screened (together with 2CFAs).
- EXT best on mechanical performance, CFA best on price, SAP is optimal and was selected.

The creation of surface modified nanoclays compatible with fibre reinforcement cement and cement foams enabling uniform dispersions for up to 10 Vf% of nanoclays

- Laboratory tests have been conducted with different percentage of organic modifiers.
- Scaling up the modifying process from the laboratory to the plant has been conducted
- Viscogel XDS - the brand name for modified bentonite, developed as part of the FIBCEM product, has been industrially produced and manufacturing volume is expected to reach about 100 tons in 2015

Development and Implementation of polymer-based modular extrusion screw to save 30% energy

- The polymeric modular screws were developed and used very successfully, since the materials processed were at room temperature there was no distortion of screws detected and the wear characteristics were very similar to that of the wear characteristics of the metal screws.

Extrusion die development for co-extrusion of cement foam core and FRC based skin

- An aluminium co-extrusion die has been developed, manufactured and tested
- Skin & core were well extruded separately using the core extrusion die. Samples produced using this method were used for some of the performance testing
- Co-extrusion of core and skin proved to be very challenging due to the different rheology between the skin and the core and problems with the dispersion of the fibres in the skin. This caused significant problems in the extrusion of the skin material with a thickness of 2mm while reinforced by 4mm-long discrete fibres
- The Project consortium evaluated countermeasures to produce co-extruded material but concluded that to achieve a FIBCEM material that could lead to a commercially viable product a “Plan B” material would be developed. The “Plan B” material developed was based on a single extrusion process of a single composite material that combines the properties of the skin and the core
- Samples of the Plan B material were successfully made using the developed extrusion process

Material composition optimized for low energy extrusion of FRC skin material containing up to 10Vf% of polymer fibre and 10Vf% nanoclay

- Fibre cement skins specially designed for extrusion that are initially dry and only become wet during mixing have been developed.
- The skin has a low water to powder ratio and the powder component combines well with nanomaterials (particularly colloidal silica).

- The skins provide appropriate engineering, deformation, durability and permeation properties.
- The structure of the skins has been characterised by low porosity and by an initially polymer-like microstructure.

Potential impact and main dissemination activities and exploitation results

Due to difficulties encountered during the implementation of the dual extrusion process the consortium formulated an alternative plan, “Plan B”, to ensure that on completion of the project, the developed material could be developed into a commercial product within a shorter timescale than that envisaged for the dual extruded sandwich material.

The final summarised test results and described potential impacts, are based on using the formulation developed as part of the plan B. This developed formulation defined as “Mix 4B” was based on a single composite material that used a combination of the core and skin materials

The tested samples described in this summary were made using the Mix 4B formulation but were processed by either a cast/compress, cast/rolled or single extrusion process.

This single composite material is referred to as “FIBCEM Plan B”

The developed skin/core/skin sandwich structure is referred to as “FIBCEM Sandwich”

Compared to the Integration performance objectives the following final results have been achieved:

Low energy consuming extrusion process for novel cement sandwich material capable of producing sheet material with thickness of 2 mm to 25 mm

A low energy extrusion process has been successfully developed. The developed core and skin materials have been extruded separately using the core extruder and a FIBCEM sandwich material has been made by combining these layers after the extrusion. A co-extrusion sandwich material of acceptable quality could not be made with the 2mm skin, due primarily to difficulties with the dispersion of 4mm-long fibres within the material.

A sandwich material with the following improvements in properties compared to reference CEMBRIT FRC based product

Testing of the FIBCEM plan B material has shown that the following achievements against the initial implementation objectives.

Density decrease: 10 – 50%
Achieved (18% decrease): A density of 1.40 g/cm^3 was achieved for the Plan B material against a CEMBRIT reference material of 1.70 g/cm^3

Flexural strength increased by 20%
Not Achieved (46% reduction): A flexural strength of 13Mpa for the Plan B material was achieved against a target of 24MPa. However the Skin material developed for the FIBCEM sandwich achieved a flexural strength in the range of 25 to 35 MPa (4 to 46% increase)

Increased shear strength by 20%
Not Achieved. The shear strength of the sandwich material was not measured, due to not being able to make the FIBCEM sandwich material.

Charpy Impact Strength increased by 30%

Not Achieved (49% reduction): A Charpy impact strength of 1.8 kJ/m^2 was achieved against a target of 3.5 KJ/m^2. This is due to the Plan B composite material not having the strong skin properties that were incorporated in the Skin material developed for the FIBCEM sandwich.

Thermal conductivity decreased by at least 20%

Not Achieved: The thermal conductivity of the plan B material was almost identical to the CEMBRIT reference of 0.18 W/m^{O}C

Water absorption (wet over dry) reduced by 30%

Achieved: The water absorption target was achieved for the developed high density skin material used in the FIBCEM sandwich, but was not achieved for the plan B composite material.

Fire Rating of A1

Achieved: A fire rating of A1 was achieved when tested against the specification: " Reaction to fire tests for building products – Non-combustibility test (ISO 1182:2002)"

A reduction of up to 50% in the amount of cement used compared to equivalent conventional FRC

A Life cycle assessment has been performed which shows a reduction on cement content from 78% for conventional fibre cement boards to 34% for the FIBCEM plan B material (Mix 4 B formulation). This represents a reduction in cement of over 50%.

The CO2 emissions from the FIBCEM Plan B material are less than 50% of that from conventional FRC based products due to the reduction on the cement content.

A total production cost for the material in the form of roofing tiles and siding no more than 5% greater than current equivalent material.

Due to the nature of this R&D project involving a small scale manufacturing (in this case extrusion) of fibre-cement materials, it is difficult to estimate the production cost and compare with that of current equivalent material with data of large scale production being available and reliable. It is expected that as production scale increased, the production cost of per unit produced material will decrease.

'Cradle to grave' Life Cycle Analysis of the material and extrusion process using the International Reference Life Cycle Data System (ILCD) created by the European Platform on Life Cycle Assessment.

A life cycle assessment has been performed using details of the production process of the FIBCEM Plan B material (extrusion process and raw materials). The LCA analyses the impact of raw materials, transport and production impacts.

The life cycle assessment shows that the FIBCEM Plan B material offers better environmental results in all impact categories compared to equivalent commercial products.

Cement is the most pollutant material in all analysed concepts, such as general emissions, inorganic emission to air, CO2 and impact categories.

Due to the fact that in FIBCEM plan B material, cement is mostly substituted by some additives, it can be observed a significantly improved environmental behaviour than the commercial materials with higher quantities of cement.

Potential Impacts

The developed FIBCEM Plan B material is a low density material with reduced CO2 emissions and similar acoustic and thermal properties and fire proof capability compared to existing FRC based products.

Although this material does not have the high density & strength skin which was intended to resist the harsh conditions of the intended environment for the product, the material could be exploited in Internal building applications.

To exploit this material, further development would be required to verify and optimize the performance of the Plan B material and to validate the material in the particular application that it is targeted to.

The manufacturing process to be used could be extrusion, though based on single layer extrusion as extrusion of 2 mm thin layers with 3 to 4 mm fibres is considered as impossible. A pilot manufacturing plant would need to be built and products installed in application to verify performance over time.

Such developed product can offer significant benefits over existing FRC based products due to the reduction in the CO2 footprint caused by the reduction in the amount of cement in the material; the low energy manufacturing process; and the low density of the material which leads to lower production and transportation costs.

The material also offers better environmental results in all impact categories compared to equivalent commercial products.

Main Dissemination activities

The main dissemination activities have been through the presentation at conferences and the publication of papers in scientific journals.

	Conference	Date / Place	Author(s)/Partner	Title
1	Computational modelling of concrete and concrete structures (EURO-C 2014)	24th -27th March 2014, Austria	Ismael Viejo, Manuel Laspalas / ITA	Consideration of fibre orientation in a stochastic model of strain hardening cement composites
2	NANOSMAT Conference	24th September 2013 (Granada, Spain)	María del Carmen Maestre Casas/ Acciona	Nanocomposites on their way to Commercial Success
3	User' meeting Digimat 2013	8 – 10th October 2013 Belgium	Ismael Viejo, Manuel Laspalas / ITA	Prediction of the flexural behaviour in a cement-based sandwich composite by means of multiscale process with DIGIMAT FE, MATLAB and ABAQUS
4	RILEM International Conference	2 – 4th September 2013 Paris, France	Xiangming Zhou / UBRUN	Experimental Techniques for Characterising Rheology of Fibre Reinforced Cement-based Materials for Extrusion
5	3rd All-Russia (International) Conference on Concrete and Reinforced Concrete	12-16th May 2014 Moscow, Russia	BATH	The effect of the addition of two dispersed montmorillonite clay nanoparticles on the strength and microstructure of blended Portland cement pastes
6	2014 International Concrete Sustainability Conference	12-15th May Boston, USA	BATH	The effect of the addition of two dispersed montmorillonite clay nanoparticles on the strength and microstructure of blended Portland cement pastes
7	IIBC 2014 International Inorganic-Bonded Fiber Composites Conference	15-19th Sept. 2014 Da Nang, Vietnam	Cembrit	
8	Nicom5 Fifth International Symposium on Nanotechnology in Construction	24-26th May 2015 Chicago, USA	BATH	Dispersed and modified montmorillonite clay nanoparticles for blended Portland cement pastes: Effects on microstructure and strength
9	ACSEE2014, The 2nd International Conference on Advances in Civil, Structural and Environmental Engineering	25-26 October 2014, Zurich, Switzerland	UBRUN / Xiangming Zhou, Hua Rong,	"Characterization of Rheology of Fresh Cement-based Materials for Extrusion via Direct Shear Test"
10	34th Annual Cement and Concrete Science Conference,	14-16 September 2014, Sheffield, United Kingdom	UBRUN / Xiangming Zhou, Zongjin Li	"Manufacturing Cement-based Materials and Building Products via Extrusion"

11	Gordon Research Conference on Advanced Materials for Sustainable Infrastructure Development,	3-8 August 2014, Hong Kong.	UBRUN / Xiangiming Zhou	Simulation of Fresh-state Mechanical Properties of Fiber-reinforced Semi-solid Cement-based Materials for Extrusion”

Papers

	Title	Date	Author(s)/Partner	Potential journals
1	Design of Porous Cement Based Materials’	August 2013	Luis P. Esteves, Ole M. Jensen/ DTU	
2	Thermal analysis of cement pastes with superabsorbent polymers	TBA	Luis P. Esteves, Ole M. Jensen/ DTU + LEI	
3	A continuum material model for strain hardening cement composite	2015	ITA-BATH	• Engineering Fracture mechanics (1.353) • Cement and concrete composite (2.427)
4	Numerical modelling mechanics of porous cement-based materials by superabsorbent polymers	2015	ITA-DTU	• Engineering Fracture mechanics (1.353) • Cement and concrete composite (2.427) • Cement and concrete research (2.781)
5	Multiscale framework for modelling a cement-based sandwich composite	2015	ITA	• Engineering Fracture mechanics (1.353) • Cement and concrete composite (2.427)
6	Effects of nanosilica on the calcium silicate hydrates in Portland cement-fly ash systems	20/11 2013	BATH	• Cement and Concrete Research • Advances in Cement Research
7	Influence of the organically modified nanoclay on properties of cement paste	6/12 2013	LEI	•
8	Modification and characterization of MBDHTA+ intercalated nanoclay	11/4 2014	LEI / LCM	•
9	The effect of the addition of nanoparticles of silica on the strength and microstructure of blended Portland cement pastes.	12/5 2014	BATH	•
10	Proceedings of Institution of Civil Engineers-Civil Engineering	2015 UK	Xiangming Zhou / UBRUN	Manufacturing of Concrete-based Building Products via Extrusion: from Laboratory to Factory

Main Exploitation Results

The following exploitable results have been achieved from the project:

1. Nanoclay cement reinforcement
2. Chemical foaming agent for cement
3. SAP based foaming agent for cement
4. Energy Efficient Extruder and Die industrial design
5. Computer Model of Extrusion of Cement based Building Materials
6. FIBCEM Material Concept
7. Computer Model of FIBCEM Material

Exploitable Result	Type	Partner	Status
Nanoclay cement reinforcement	Patent	LEI	NA
Chemical foaming agent for cement	Patent	Sika	NA
SAP based foaming agent for cement	Patent	DTU	NA
Energy Efficient Extruder and Die industrial design	Industrial design/Patent	UBRUN WCMP	(NA)
Computer Model of Extrusion of Cement based Building Materials	Copyright	UBRUN CE	Achieved
FIBCEM Material Concept	Patent	Cembrit	NA
Computer Model of FIBCEM Material	Copyright	ITA	Achieved

As the project did not achieve any patentable results no plan or agreement for patenting has been made. The computer models made and used to evaluate the FIBCEM material are copyright protected by the relevant partners.

The extruder and die design can be further assessed and at a later stage is likely to be protected by Industrial design or patent.

The final FIBCEM material that was developed and tested used a “Plan B” formulation.

The Plan B was initiated due to difficulties related to extrusion caused by different rheology between skin and core and problems with dispersion of fibres making extrusion of the skin impossible in thickness 2 mm. In plan B we mixed core and skin which in general solved the issue with extrusion of 2 mm thin skin. It did not solve the problem with dispersion of fibres.

We decided to mix and press the plan B material instead of extrusion to have the relative high number of samples available and in a quality which was worthwhile testing.

The outcome of the plan B is very different from the work described in the DoW. The outer skin which was supposed to have the high density to resist the harsh condition in real life is now reduced considerable. This means that we perhaps more are developing a product for internal use. Secondly we do not have the extrusion in place. We have made the material for test. The basic for this recipe used in plan B has due to limited time been selected by a few tested recipes. In the ideal world this number of recipes would have been much higher.

To transition to commercial production the plan B material will need further optimization and testing. The implementation steps required to achieve a commercial implementation are:

- Fully verify the output of the plan B.
    - We will have an indication of the performance.
- Continue the optimization of the recipe 4 B, if concluded feasible,
- Validate in which application the plan B material can be used
- Carry out test further depending on application for the product.
- Test a full size product, which requires the building of a pilot plant.
- Install the product/products to be able to analyze the performance over time.
- If performance is found to be acceptable then an investment in new production equipment can be made.
- The timeline for starting the investment will be in the range of 3 to 5 years minimum depending on the product application.

Address of project public website and relevant contact details

Please see www.fibcem.com