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0 Executive summary

This deliverable is a review report which evaluates the progress and feasibility of the biocomposite systems, designs and installations, taking into account the information resulting from the work developed in the aim of Biobuild project.

The main steps followed in the project up to this moment to develop bio-systems with such characteristics can be summarized as follows:

- Use of additives and modifications to create durable natural fibres.
- Use of additives and modifications to create durable bio-based resins.
- Combine the improved resin and fibres to create durable and strong biocomposites.
- Combine the improved natural fibres, resins and core materials to make composite components having mechanical properties, durability and functionality suitable for the selected construction applications.
- Produce panels, profiles and sandwich structures for the selected construction applications.

In terms of baseline resin/fibre properties, it was concluded that for both fibre reinforced composites (flax and jute fibre reinforced UP and epoxy composites) the increased moisture absorption is accompanied by a decrease in longitudinal stiffness and strength and by an increased plasticity, leading to an increase in longitudinal strain-to-failure. In general, the longitudinal stiffness of flax fibre composites decreases to 1/2 of its initial value, whereas that of jute fibre composites only goes down to 1/3 of its initial stiffness. On the other hand, the longitudinal strength of jute fibre composites is decreased by 1/4 after immersion, while that of flax fibre composites is only decreased by 15 %. Finally, for both fibre composites, the longitudinal strain-to-failure is increased by around 50 %.

After the completion of the flax preforms benchmarking, these observations were made:

- No significant difference between the different UD preforms tested in longitudinal direction.
- The higher value of the transverse tensile strength for the Procotex UD is mainly due to the binding yarns.
- Jute preform, as shown in the previous section, has lower property values than flax, but will still be relevant for low cost and non-structural parts. The same conclusion applies for the mat preform.
- Tensile testing is defect sensitive which may explain the variations in results.

Concerning the effect that fibre treatments have on the durability and moisture resistance, it was concluded that:

- Quality of the samples makes difficult (impossible) to measure the effect of fibre treatment on the properties of the composite boards.
- Water uptake is the main technical drawback for biocomposites.
- Sealed edges and coating are other possibilities to improve the properties.
- Jute is more water resistant; further examination is required for composites used in outdoor conditions.
- None of the fibre treatments has a clear positive effect on the properties (water uptake nor strength) of the composite boards.
- Research on fibre treatment within the project is needed for fundamental understanding and examining the possibilities for the future.

The ongoing work in WP3 consists essentially in refining the processability of the various sandwich configurations in order to optimize the process parameters (time, temperature, pressure, degasification cycles, etc.) and to minimize rejections and wasted material (either from a failed production cycle or from corrections in final dimensions) with the target of obtaining panels that are fit for the tasks they are intended for.

Currently, the work on this task is far from finished, since on one hand problems regarding medium scale production are yet to be solved and on the other hand this is a task which should follow the development of the products, especially if, in the testing phase (including the Single Burning Item test and other equally important tests), it is found that any of those sandwich panel configurations need to be adjusted in order to comply with the target technical requirements.

The main conclusion drawn from the processing of furan resin and glass fibres can be summarised as follows:

- Furan resins have a very low reactivity (which can be increased) which means that pultrusion speed should be very low, making the process not economically viable from an industrial point of view.
- The acid catalyst required to cure the resins and the high processing temperature required for the production induces fibre degradation and corrosion of steel parts in the production equipment. The action of acids can cause hydrolysis in cellulose chains and other binding materials, thereby degrading the fibre bundle mechanical properties.
- It was therefore evident that this furan resin was unsuitable for use with natural fibres due to the acidic catalyst used to cure it.

From the processing point of view, the first results of bio-polyester resins in combination with flax fibres can be summarized as follows:

- The processing conditions for bio polyester resin are very similar to that of traditional resins, therefore similar pultrusion speed and heating temperature are used and similar resin stability are obtained.
- The main drawbacks arise from the natural fibres. Dry natural fibres, when compared to glass fibre show fibre buckling, fibre rupture and fibre blockage near and in the mould.
- In order to solve these issues, zinc stearate was added to the formulation and better results were obtained. More tests are underway to determine the proper additive concentration.
- In principle this seems to be the best option in order to manufacture pultruded profiles with natural fibres and bio-resins.

The main conclusions drawn from mechanical testing are summarized below:

- Furan resins contains different amounts of water which, in conjunction with the water produced during the curing reaction, leads to pultruded profile with high void content and consequently poor mechanical properties.
- In general low viscosity furan resins contain more water and lead to more porous composite materials with lower mechanical performance.
- Furan resins with lower water content have higher viscosities, which prevent a good impregnation of reinforcing fibres and consequently produce pultruded panels with poor mechanical properties.
- The third option is to select furan resins with higher reactivity, but even if this will have a positive effect on pultrusion speed (higher) it would decrease pot life and make it very difficult to work with. Obviously, lower reactivity leads to lower pultrusion speed and longer pot life but from an industrial point of view the process seems not to be economically viable.

The BioBuild project entails the design and construction of four case studies, namely: an External Wall Panel (EWP), an External Cladding Kit (EKC), an Internal Partition Kit (IPK) and a Suspended Ceiling Kit (SCK). All systems have been assessed on specific criteria, including fire-safety; dimensional stability; in-service resistance to loads; thermal and acoustic insulation; energy efficiency; and sustainability. The assessment of their performance is the aim of WP6.

Aiming to evaluate the mechanical properties of each composite, the tensile and flexural properties of the composites were assessed according to the previously defined test plan; however, some modifications were made to the plan due to the insufficient amount of material that was made available to LNEC in respect to what was requested. All tests were performed at ambient temperature, except in case of the heat deflection temperature (HDT) test.

From the results obtained it is possible to conclude the following:

- The compression-moulded flax/furan sample shows the best performance and higher mechanical strength, when compared with the other samples tested (lamella sandwich of UP and 0/90º jute fabric on surfaces and cork in the core, and flax/furan on surfaces and thick cork prepreg in the core).
- The composite constituted by flax/furan on surfaces and thick cork prepreg in the core, which is designed from sample 3 but adding cork to the core, shows delamination, even before testing. Thus, techniques to modify the surface/interface/interphase should be improved, in order to assure a performance similar or better than the composite without the inner cork layer.

Additional work is still being done for a better performance evaluation of the referred composites. More samples are also needed in order to have a complete picture of the mechanical properties of all composites.

So far, the initial ignitability tests on the basic performance of the materials showed that:

- Furan resin does not ignite easily.
- Furan/flax prepregs may ignite and sustain a slow propagation of combustion.
- Flax (non-woven) mat is easily ignited and flame spreads very rapidly with total combustion being the final result.
- Degradation of the furan surface (cracking, delamination, blistering) exposes the natural fibre reinforcement that will sustain combustion.
- On the contrary, Biopol resins ignite (flame edge attack) and sustain the development and propagation of flame resulting in the total combustion of the material.
- As expected, if agglomerated cork layers are exposed to flame attack they will ignite (easily if thickness is small) and sustain combustion.
- Edges must be protected (in the end product/kit). Practical/cost effective solutions must be studied.
- So far, only a RtF class E is “guaranteed” for most of the different component/material solutions assessed.

1 Introduction

The overall aim of this project is to create new biocomposite construction systems which can replace high embodied energy materials currently in use (e.g. aluminium, steel, brick, concrete, and glass fibre reinforced polymers – which are mostly derived from non-renewable petro-chemical and mineral origins and produced by energy intensive synthesis), significantly improving the environmental impact and sustainability of the European building industry.

BioBuild will fulfil this goal by introducing and broadening the use of biocomposite material systems in order to reduce the overall embodied energy that is created for the building of facade, supporting structure and internal partition systems by at least 50 % over current materials without extra cost.

Therefore, the result of the project will be a low cost, lightweight, durable and sustainable biocomposite building system for both new-build and refurbished structures, based on panels, profiles, frames and sandwich structures, with full technical and environmental validation, which will allow the construction of low embodied energy large-scale facades, support structures and partitions.

FRP’s are known as a good solution to reduce embodied energy partly due to their light weight and high stiffness, which allows them to be used sparingly, and also due to the design flexibility that they allow, which can be used to create very efficient structures. In spite of the rapid development over the past four decades, the widespread use of FRP’s within the construction industry has been relatively slow due to entrenched practices and lack of incentives to change from the current relatively low cost, but high embodied energy materials.

The use of natural fibres in composites instead of the usual glass and carbon fibres is being developed in a number of industries. Flax and other natural fibres have excellent resistance to fatigue and good vibration damping compared to glass and carbon fibres. The specific stiffness of flax and other natural fibres is also higher than that of glass fibres, allowing reduced component weights when used to replace glass fibre in composite applications. In addition, several studies have shown the lower impact of flax and other natural fibres in factors contributing to climate change, ozone depletion, toxicity and eutrophication, and that the energy required for producing natural fibres suitable for composite applications is far less than for glass and carbon fibres.

Bio-based furan resins have been used in industrial applications for many years in the production of casting moulds but they have now been developed for composite use. These resins are currently used in wood-based composites and as binders in composite parts for automotive applications. Furan resins have good mechanical properties and excellent fire performance. Natural derived epoxy and polyester resins have been used to create part-bio resin systems and are now available as 100% bio systems. These materials have been previously used to manufacture composites materials reinforced with both carbon and glass fibres as well as with jute fibres. The flexibility of the chemistry of these resins allows the physical/chemical properties to be tuned in order to achieve high compatibility with fibres, together with the best choice of curing cycle, flame retardancy, chemical resistance, thermal and mechanical properties.

Whilst natural fibres and bio-resins are available and are used commercially they have not been tailored to construction industry standards. The use of flax and jute as reinforcements within a composite is known to provide characteristics equal to or better than glass, but there are still doubts over the durability of these materials in an external environment. There is growing evidence that the main factors affecting the long-term performance of natural fibre reinforcement, such as the hydrophilic nature of flax and its stability under UV exposure, can be resolved with a variety of simple chemical treatments. The resin of synthetic composites used in outdoors environments normally contains UV stabilizers, and the same can be done when they incorporate natural fibres. These treatments may also improve the bond between the fibre and the resin which ought to produce a double effect, improvement of the mechanical properties and protection of the fibres from moisture. When the fibres are protected they are less susceptible to swelling and therefore the routes for moisture ingress are further reduced.

In this project, the natural fibres are being optimised in terms of strength, surface condition for use in the pultrusion and semi-continuous feeding systems, while the resins are being chemically and physically tailored to achieve the best durability and compatibility with the jute and flax reinforcements. In addition the project aims to develop resins with high resistance to biodegradation. Consequently, the materials developed in this project are being optimized, not only, for the production techniques but also for functionality (e.g. mechanical performance, fire resistance, biodegradation resistance, porosity, fibre bonding interface) so that they can be used in a wide range of building components.

The main steps followed in the project up to this moment to develop bio-systems with such characteristics can be summarized as follows:

- Use of additives and modifications to create durable natural fibres;
- Use of additives and modifications to create durable bio-based resins;
- Combine the improved resin and fibres to create durable and strong biocomposites;
- Combine the improved natural fibres, resins and core materials to make composite components having mechanical properties, durability and functionality suitable for the selected construction applications;
- Produce panels, profiles and sandwich structures for the selected construction applications;
- Produce full-scale demonstration installations allowing full testing of the biocomposite products.

This work is been carried out in WPs 2, 3, 4, 5 and 6. Although, WP6 has just started, a deliverable is written now in order to provide an evaluation of the progress and feasibility of the biocomposite systems, designs and installations, taking into account the information resulting from the work developed in Work Packages 2, 3, 4 and 5 concerning the aim of Biobuild project. In addition, this work package will also present the results obtained thus far in WP6.

2 Reinforcement and resin development (WP2)

2.1 Baseline resin/fibre properties

The requirements of task 2.1 were to benchmark the selected fibres and matrices against current non-bio, part-bio and full-bio systems, giving a clear indication of the progress that can be made within the project. Flax and jute fibres were benchmarked with respect to their moisture uptake and their mechanical properties after moisture uptake. In a second stage, the benchmarking of flax and jute fibre reinforced UP and epoxy composites was also performed.

It is established that, at least for the individual fibres, the moisture uptake is larger for jute fibres, yielding a relative mass increase of 60% compared to around 55% for individual flax fibres at full immersion of the fibres. It is shown that the increase in moisture absorption deteriorates the flax fibres, leading to a continuous decrease in longitudinal stiffness, strength and strain-to-failure. Full immersion of the flax fibres approximately divides all longitudinal properties by a factor of two. For jute fibres, there is an optimal value of moisture absorption.

The resin benchmarking section proves that it is possible to have bio-based unsaturated polyester resins without compromising on the processing standards or performance of the product. Each application technique requires an optimization of the polymer backbone and the curing condition and therefore different versions. Already there are unsaturated polyester resins to serve the market:

- Palapreg ECO 55: SMC/BMC
- Synolite ZW 7524: artificial stone
- Synolite ZW 7820 and Synolite 7500-N-1: hand lay-up and infusion application, cold curing

For both fibre reinforced composites: the increased moisture absorption is accompanied by a decrease in longitudinal stiffness and strength and by an increased plasticity, leading to an increase in longitudinal strain-to-failure. In general, the longitudinal stiffness of flax fibre composites decreases to half of its initial value, whereas that of jute fibre composites only goes down to 1/3 of its initial stiffness. On the other hand, the longitudinal strength of jute fibre composites is decreased by ¼ after immersion, while that of flax fibre composites is only decreased by 15%. Finally, for both fibre composites, the longitudinal strain-to-failure is increased by around 50%.

2.2 Composite system feasibility assessment

The deliverable containing this assessment follows the first report D2.1 (referred to in the previous section) which addresses the baseline properties for fibres and resins. In the upcoming sections, an update of the status of ongoing investigations on flax fibre and bio-resin developments will be presented. As well, environmental credentials of the materials as well as mechanical properties and usability will be shown. Various flax fabrics were selected for this research in order to get a look and confirm literature data.

In the first phase of the biocomposites development, a selection of fibre architectures and suppliers needs to be done through an assessment of their mechanical properties. It was decided at the Q1 meeting in Leuven that the acquisition, coordination and distribution of flax fibre preforms/fabrics to the other WP2 partners will be done through KU Leuven (small quantities) and NetComposites (large quantities) for flax and IVW for small quantities of jute.

KU Leuven focused on UD (fabrics or yarns/rovings) and random mat preforms and NetComposites worked on the benchmarking of woven fabrics. Table 1~~Table 1~~ regroups the selected suppliers and benchmarking tasks. These fabrics will be compared on the basis of their mechanical properties.

Table 1 - First choice of flax fibre suppliers according to the fabric structure

KU Leuven	Selected suppliers			
UD	Lineo	Procotex	Composite Evolution	-
Yarns or Rovings	Composite Evolution	Safilin	Fimalin	Depestele
Random Mat	EcoTechnilin	-	-	-
NetComposites	Selected suppliers			
Woven fabrics	Composite Evolution	Lineo and Libeco	Fimalin	Depestele

After the completion of the flax preforms benchmarking, these observations were made:

- No significant difference between the different UD preforms tested in longitudinal direction
- The higher value of the transverse tensile strength for the Procotex UD is mainly due to the binding yarns
- Jute preform, as shown in the previous section, has lower property values than flax, but will still be relevant for low cost and non-structural parts. The same conclusion applies for the mat preform.
- Tensile testing is defect sensitive which may explain the variations in results
- Variations in results may also be caused by the choice of manufacturing process. In this case, we were expecting that the VARI results would be lower than RTM, and the latest giving also lower performance than Autoclave. The disadvantages of the autoclave process are its high cost and low volume of production.

These observations allowed to make choices of the preforms to be kept for further investigations and benchmarking of flax composites combined with bio-matrices as well as for the study of the chemical treatments influence on the performance of the part. Fimalin and Depestele were taken out of the potential suppliers list due to sourcing problems (Table 2~~Table 2~~).

Table 2 - Final fibre architecture choices

KU Leuven	Selected suppliers			
UD	Lineo	Procotex	Composite Evolution	-
Yarns or Rovings	Composite Evolution	Safilin	~~Fimalin~~	~~Depestele~~
Random Mat	EcoTechnilin	-	-	-
NetComposites	Selected suppliers			
Woven fabrics	Composite Evolution	Lineo and Libeco	~~Fimalin~~	~~Depestele~~

2.3 Effect of fibre treatments on the durability & moisture resistance

The requirements of task 2.3 are to give an initial report on the improvements of durability and moisture resistance of natural fibre composites due to applied fibre treatments. Regarding the improvements in compatibility between fibres and matrix, it is remarked that most treatments are performed on flax fibres, while it is assumed that the results are straightforward transferable towards jute fibres, given their similar chemical composition. Flax and jute fibre composites were benchmarked with respect to their moisture uptake and several treatments have also been evaluated on moisture uptake.

In order to evaluate the compatibility between untreated flax fibres and the chosen bio-epoxy system from Cimteclab[1] (output from deliverable D2.2) and in order to evaluate the effect of fibre treatments, a series of transverse three point-bending tests was carried out. For alkali treatment, the results of the first transverse three point bending tests show that moderate concentrations and short treatment times lead to the most beneficial improvements in transverse three-point bending results. It can furthermore be seen that a combination of high alkali concentration and long fibre exposure times result in a detrimental decrease in transverse three-point bending strength. Presumably, this is due to a degradation of the fibre mechanical properties, induced by a change in fibre structure.

It was further investigated whether a specifically chosen silane system (3-aminopropyl-tri-ethoxysilane - APS) can further improve the transverse three-point bending properties. The underlying idea behind this hypothesis is that an alkali fibre pre-treatment increases the amount of hydroxyl groups that are present at the surface of the technical flax fibre and as such increases the potential reaction with the hydrolyzed APS molecules through a condensation reaction. The amino function allows a potential reaction with the epoxy matrix. In order to investigate this hypothesis, the fibres have been alkali pre-treated according to the best treatment parameters. Afterwards, both concentration and time of the APS immersion-treatment were varied. The result of the T3PB tests, performed on the by this route treated fibre composites, however did not constitute an increase in transverse flexural properties.

Next, it was investigated what the role is of the alkali pre-treatment. In this light, untreated flax fibres have been subjected to an APS solution treatment of various concentrations and treatment times. The outcome of the transverse three-point bending tests reveals that alkali pre-treatment is not required. It is necessary to mention though that, compared to an alkali treatment, APS treatment brings forth similar values in transverse flexural strength, but only reaches approximately 2/3 of the transverse flexural stiffness.

In order to demonstrate that the effect of the silane treatment on the transverse three-point bending strength is actually due to the presence of APS molecules in the solution, a fifth set of experiments was put forth. In this final set of data, the aim was to separate the effect of the two solution components on the final transverse flexural properties of the APS treated composites. To do so, a series of fibres was immersed in water for treatment times that are identical to the ones stated in the previous subsection on APS treated fibre composites. It became evident that the presence of APS molecules in the water solution is important to obtain obvious improvements in the transverse flexural properties of the composites. However, it is also deducible that just water treatment will already increase the composites transverse flexural strength and stiffness by 50%.

In order to evaluate the compatibility between untreated flax fibres and the chosen bio-UP system from DSM (output from deliverable D2.2) and in order to evaluate the effect of fibre treatments, a series of transverse three point-bending tests was carried out. Four conclusions can be drawn from this work:

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[1] Cimteclab left this research project but is still available to supply resins.

- Small concentrations of furfuryl alcohol and short treatment times lead to improved transverse flexural properties of flax fibre bio-UP composites
- Moderate concentrations of prepolymerized furfuryl alcohol treatment lead to improved transverse flexural properties of flax fibre bio-UP composites
- Addition of buffering agent does not play a significant role
- Addition of flexibilizer lowers the transverse flexural properties

In order to evaluate the compatibility between untreated flax fibres and the chosen furan resin from TransFurans Chemicals and in order to evaluate the effect of chemical fibre treatments, a series of transverse three point-bending tests was carried out. It became clear that alkali treatment and FA treatment lead to an improvement in the compatibility between flax fibres and furan resins. However, the optimal concentrations are still to be determined. DMDHEU treatment may lead to better results if the treatment parameters are optimized. On the downside, both APS and prepolymerized FA seem to be lowering the transverse flexural properties. They will therefore be discarded from future experiments. It is noted that the samples still contained a fair amount of porosities. This is now solved and will push the measured values for each treatment to a higher level. An update on this is scheduled in deliverable D2.5.

In order to pursue viable non-chemical treatments to change the surface composition of the flax fibre preforms, plasma treatments are also investigated. In this way, a fast and economical functionalization of the surface can be attained that benefits industrial implementation. Furthermore, plasma treatment allows fast screening towards which molecular entities are compatible with furan matrices. This is of particular interest since the resin is not fully understood and therefore the chemical reactions would be at best a reasonable guess. It was noted that most of the tested treated samples suffered from reasonable amounts of porosity, which hinders a reliable data analysis. This porosity was a result of inappropriate production parameters. On top of this, the samples were stored multiple days prior to processing which, with hindsight, might induce a reduction of the plasma effect. However, despite these clear negative effects, it is worth noticing that some of the proposed plasma treatments (such as CO_2 and N2+H2) actually do deliver a small increase in transverse flexural strength. These plasma results will be further investigated in the upcoming months.

The work done by IVW during the reporting period was focused on the treatment of unidirectional flax fabric (Biotex Flax Uni 420 gsm) yielding water-resistant “green” cardanol-based coatings or graftings on the fibers’ surface. Water glass (WG) and biobased monomers (e.g. PhAlk, EP-Car) were served individually and in sequential combinations as treating agents. The later allowed hybrid combination of benefits of both treating agents. The modification was done by varying the immersion sequence, e.g. WG- or PhAlk-/EP-Car-treatment at first stage which was followed by either PhAlk-/EP-Car- or WG-treatment, respectively. The influence of pre-cleaning procedure on the fibers (in acetone), WG-concentration, EP-Car- and PhAlk-type and reaction conditions on the water uptake, spectral, thermal and morphological properties was investigated. In general, significant reduction of the water uptake was observed for all treated fabrics. It was also found that EP-Car-/PhAlk-type has significant influence on the water resistance. Higher reaction temperature also resulted in lower water uptake values. Some soluble part was removed from the treated fibers after the first water uptake. However, no significant effect on the equilibrium water uptake values after first and second swelling was observed.

In order to evaluate the durability behaviour of flax (and jute) fibre composites in a fast and easy to assess way, the samples are subjected to a boiling water test for a period of two hours. In all cases the relative mass gain and increase in thickness of the composite specimen were recorded. It is shown that the bio-UP performs equally well as the standard polyester in terms of moisture absorption (2.5 wt%) and swelling behaviour. With respect to the polyester samples, the furan composites take up slightly more water, leading to an absorption level of around 3.5-4 wt%. Regarding the investigated treatments, it becomes clear that DMDHEU to the current extent is unable to increase the moisture resistance of the bio-UP composites. It does show a mild improvement in the moisture resistance of furanic composites. It is further noticed that jute fibre composites have an overall smaller water uptake than their flax counterparts, reducing the relative mass gain to around 2 wt%. Finally, the effect of sealing the edges to avoid facilitated water penetration through the open fibre ends was investigated. In general, it is visible that the sealed edge composites give rise to a reduction of moisture absorption in the given time scale by a factor of two. Especially for the non-woven composites, this reduction is extremely significant given the high initial water uptake (around 10 wt%).

3 Integration of coating, joining and sandwich technologies (WP3)

3.1 General

Due to the bankruptcy of Cimteclab and the corresponding discussions on the internal reorganization of work package 3, the work on adhesives has experienced significant delays. Currently, a significant effort is in place to recover the lost time and get back onto track, but the first results will be available only in December. The investigated adhesives will include a two-component epoxy system, a one-component acrylic, a two-component polyurethane and two iso-cyanates. The investigated set-ups will be steel to steel, Al to Al, Al to steel, furanic composite to furanic composite, polyester composite to polyester composite and both of the composites also to Al and steel individually. Testing will comprise of double lap shear tests in ambient conditions.

3.2 Aims

Task 3.4 (Sandwich Structures) inserted within WP3 (Integration of coating, joining and sandwich technologies) aimed to develop different sandwich structures that could accommodate the needs defined in the product design phase.

Since these sandwich panels are the elements that will equip the final products with their respective set of individual properties, this task had to be looked upon not only from a dimensional or geometrical point-of-view but also from a more technical one. This means that properties like mechanical resistance, thermal and acoustical insulation, in service aging and deterioration, fire, smoke, and toxicity behaviour, etc. had to be considered during the development of aforesaid elements.

However, while some of those characteristic are possible to be incorporated by the sandwich panels themselves others will need to be provided by additional elements. This is the case of the resistance to atmospheric elements as well as the fire, smoke and toxicity behaviour, these needs to be addressed by the application of coatings and sealants (to be explored in tasks 3.1 and 3.2).

3.3 Options considered

One of the main objectives of the BioBuild project is to reduce the embodied energy (energy required to produce a determined component from its raw materials) in construction materials making them high performance, economical, and sustainable. This means that an obvious choice is the utilization of natural materials, or at least partially natural, in the sandwich panels and, as such, bioresins were considered from the beginning, being settled a choice for Furan resins. A similar selection process inevitably implied that the fibres to be used in conjunction with the Furan resins should also be from a natural source. In this case flax and jute fibres woven and impregnated before panel production, meaning jute and flax prepregs, were selected.

In addition to this another natural, renewable, and recyclable material was selected: cork. This time to be used as a core material in the sandwich panels that later will form the different target products. This material was used in the form of agglomerated cork sheets or rolls produced using granules of natural cork obtained by grinding natural cork strips from which cork stoppers were previously extracted.

Production materials selected opened a range of possibilities for different combinations between them (thicknesses, number of layers, different material combinations, etc.), a fact which was taken advantage of in the product design phase resulting in different combinations for each of the products envisioned: IPK (Internal Partition Kit), ECK (External Cladding Kit), SCK (Suspended Ceiling Kit), EWP (External Wall Panel). At the time of writing this document the design was defined as described in Table 3~~Table 3~~.

Table 3 – Panels composition

Product	Top Layer	Core	Bottom Layer	Total Thickness
IPK	Jute Prepreg 2 Layers	CoreCORK NL20 8 mm	Jute Prepreg 2 Layers	10 mm
ECK	Flax Prepreg 2 Layers	CoreCORK NL20 4 mm	Flax Prepreg 2 Layers	6 mm
SCK	Flax Prepreg 1 Layers	CoreCORK NL20 2 mm	Flax Prepreg 1 Layers	4 mm

3.4 Summarized results

Resulting from the progresses made on this task are several panels made not only at laboratorial scale but also at a medium scale with industrial equipment. Some of those resulting panels and processing parameters can be seen in Table 4~~Table 4~~ and Table 5~~Table 5~~.

Table 4 – Processing parameters for ECK

ECK	Trial 4
Temperature	155 ºC
Pressure	10 bar
Time	6 min + cooling
Sample Size	500x500 mm
Core	NL20 6 mm
Skins	2 layers flax-furan prepreg each side
Degasification Cycles	4 times in 10 sec intervals

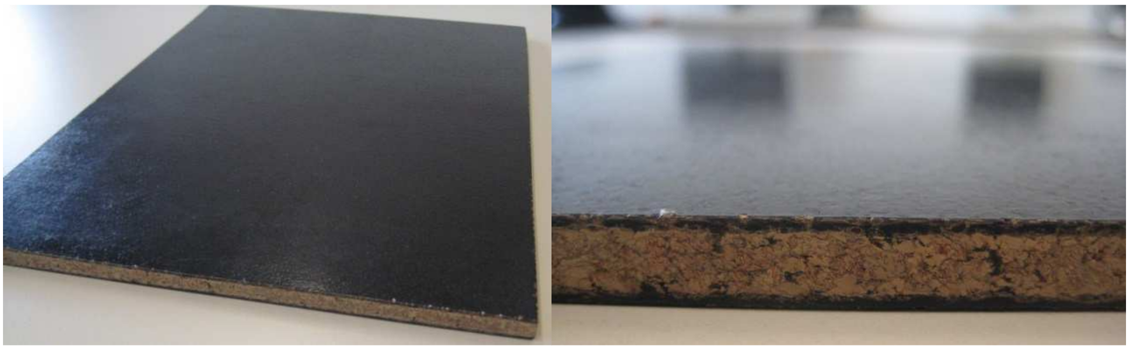

Figure 1 - ECK Trial 4

Table 5 – Processing parameters for IPK

IPK	**Trial 1**	**Trial 2**
Temperature	140 ºC	120 ºC
Pressure	TBD – 8 mm stoppers	TBD – 8 mm stoppers
Time	7.5min	12.5min
Sample Size	1500x800 mm	1500x800 mm
Core	NL20 12 mm	NL20 12 mm
Skins	2 layers jute-furan prepreg each side	2 layers jute-furan prepreg each side
Degasification Cycles	0.5 min - 1.5 min - 2.5 min - 3.5 min - 4.5 min	2.5 min - 4.5 min

Figure 2 – IPK Medium Scale Trial 1

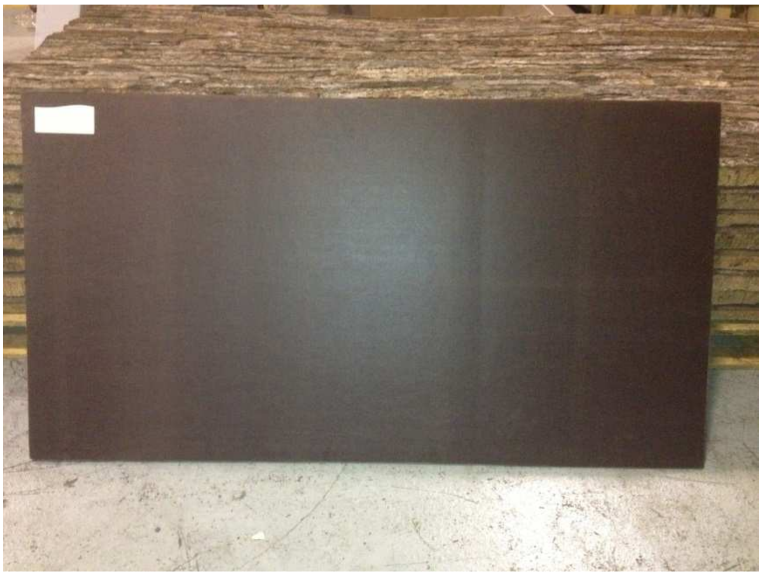

Figure 3 – IPK Medium Scale Trial 2

3.5 Ongoing work, difficulties, and additional work still to be done

Ongoing work consists essentially in refining the processability of the various sandwich configurations in order to optimize the process parameters (time, temperature, pressure, degasification cycles, etc.) and to minimize rejections and wasted material (either from a failed production cycle or from corrections in final dimensions) with the target of obtaining panels that are fit for the tasks they are destined for.

As can be deduced from the text above the developments on this task are yet far from finished since in one hand some problems regarding medium scale production are yet to be solved and in the other hand this is a task that should fallow the development of the projects, especially if in the testing phase (that includes the Single Burning Item test and others highly important) it is found that any of those sandwich panel configurations need to be adjusted in order to comply with the target technical requirements.

4 Processing of biocomposite panels and profiles (WP4)

4.1 Aims

WP4 aims to develop a series of manufactured panels and profiles combining the materials developed in WP2 and WP3 that is, natural fibre textiles, bio-resins, and cork composites. For this purpose a variety of reliable processing methods for standard composite materials will be adapted and optimised for biocomposites. The processing techniques which need to be controlled and modified are RTM, hand lay-up, vacuum bagging, compression moulding, continuous processing, semi-continuous compression moulding, and pultrusion (see Table 6~~Table 6~~).

Aspects relating to continuous processing (Task 4.2) are dealt with in chapter 3 – Integration of Coating, Joining and Sandwich Technologies.

Table 6 – Processing techniques application

Process	**Panel**	**Profile**	**Sandwich**	**Application**
RTM	+		+	Small and large scale panels for testing
Hand lay-up	+			Simple, single skin panels for testing
Vacuum bagging	+		+	Small and large scale panels for testing
Compression moulding	+		+	Small scale panels and sandwiches for testing
Continuous processing	+		+	Large scale panels and sandwiches
Semi-continuous CM	+	+	+	Large scale profiles, panels, and sandwiches
Pultrusion		+	+	Profiles as supporting structures for large panels

4.2 Options considered

4.2.1 RTM/ Hand Lay-up/Vacuum Bagged Panels (Task 4.1)

Vacuum bagging was performed by Acciona to produce lamellae combining cork, natural fibre textiles and mats, and biopolyester resin. Biopolyester resin Synolite ZW 7483 was supplied by DSM. Three different laminates were prepared using flax non-woven mat as core material and two laminates using cork as core. The skin was made of jute twill textile which was cut in +45/-45 and 0/90 direction. Table 7~~Table 7~~ shows the details regarding the configurations tested.

Table 7 – Tested configurations for lamellaes

Skin	Core	Fibre orientation
Jute twill	Cork	0/90
Jute twill	Cork	+45/-45
Jute twill	1 – flax mat	0/90
Jute twill	1 – flax mat	+45/-45
Jute twill	2 – flax mat	0/90
Jute twill	2 – flax mat	+45/-45
Jute twill	3 – flax mat	0/90
Jute twill	3 – flax mat	+45/-45

Pictures in Figure 4~~Figure 4~~ show the different steps needed to produce these lamellae by vacuum assisted infusion:starting (top left) with the resin preparation/mixing, cutting of jute twill, infusion, and finally sectioning and cutting.

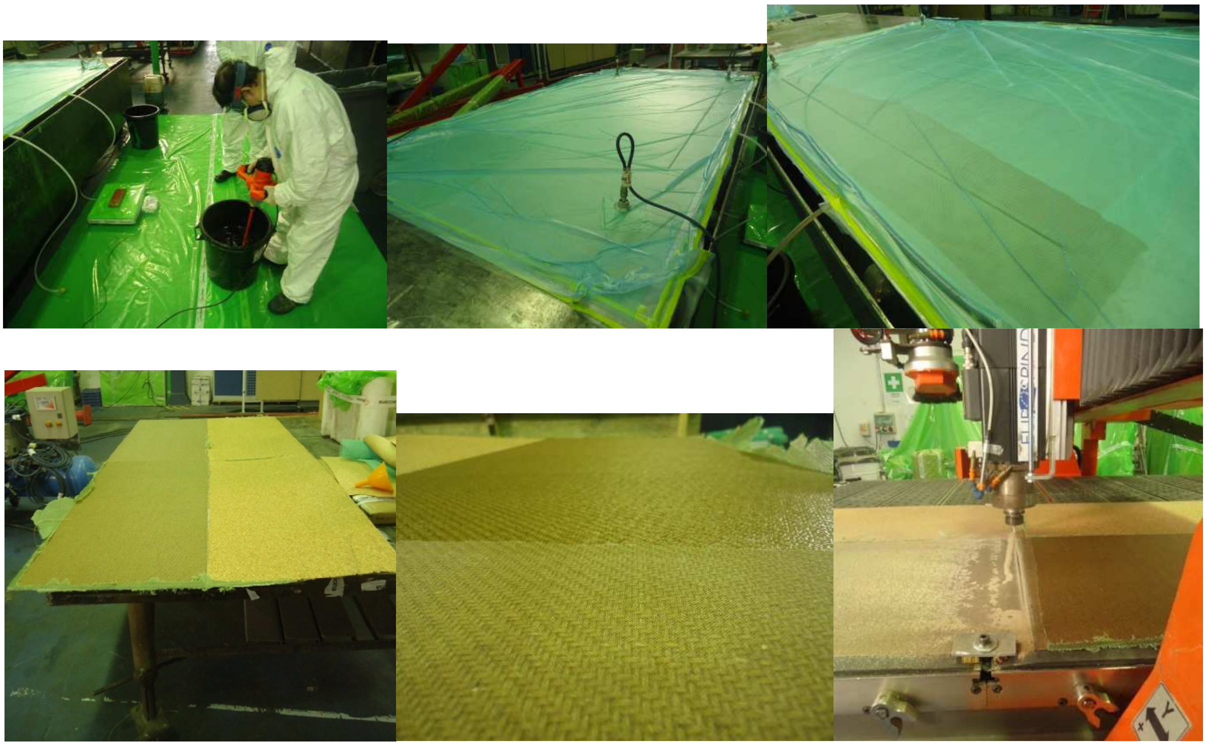

Figure 4 - Preparation and cutting step of jute/cork/jute lamellas

4.2.2 Semi-Continuous Compression Moulding Process (Task 4.3)

This task aims to optimise the semi-continuous process for use with natural fibres and furan resin in order to produce continuous, homogeneous profiles and panels with and without cores. Since the semi-continuous process is relatively new, it requires some material-form development, particularly regarding the resin flow.
The semi-continuous compression moulding machine (CCMM) works on the basis of a semi-continuous process which consists of an alternating press and transport stages. During the pressing stage a constant pressure acts on the laminate (see Figure 5~~Figure 5~~). At the subsequent stage the top of the pressing tool moves up and a feed unit pulls the laminate ahead. For each stage the period of time can be adjusted separately. Thus, a complete press cycle comprises the following steps: closing, pressing, opening, and transporting.

Once these four steps are completed, a new cycle begins. To prevent adhesion of the molten material to the mould halves, the material is transferred through the system between two release surfaces. Depending on the process temperature, paper, foil, or sheet steel is used. Furthermore, the release surfaces serve as transportation aids.

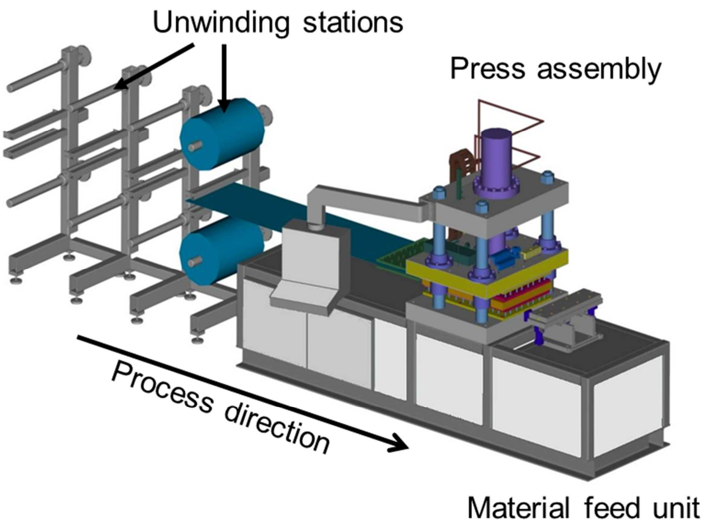

Figure 5 - Semi-continuous compression moulding machine schematically

4.2.2.1 Small scale – static compression moulding

The first trials were carried out at a small scale static compression moulding machine in order to estimate the optimal process parameters for natural fibre reinforced furan resin. The textiles used were flax twill and jute twill and the process requires prepregs, which were delivered by NetComposites. The fibre weight fraction of the flax prepregs was 37 %, whereas the fibre weight fraction of the jute prepregs was 31 %.
The process parameters are as shown in Figure 6~~Figure 6~~. Due to the polycondensation reaction of the furan resin, water steam occurs during the process and the mould has to be lifted four times to let the water evaporate. Due to the foaming characteristic of furan resin the resin escaped out of the mould during the first trials, which has to be cleaned after every press process (see Figure 7~~Figure 7~~). Obviously, the material could not be used in the semi-continuous process in this way. The excess flow is about 15%. One proposal to solve the resin problem was to increase the fibre weight fraction in both materials.

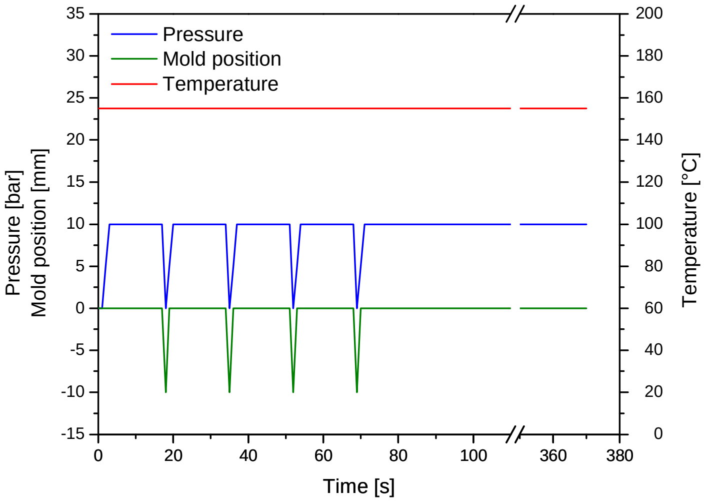

Figure 6 - Process parameters for the production of flax-/jute-furan composites at a static press

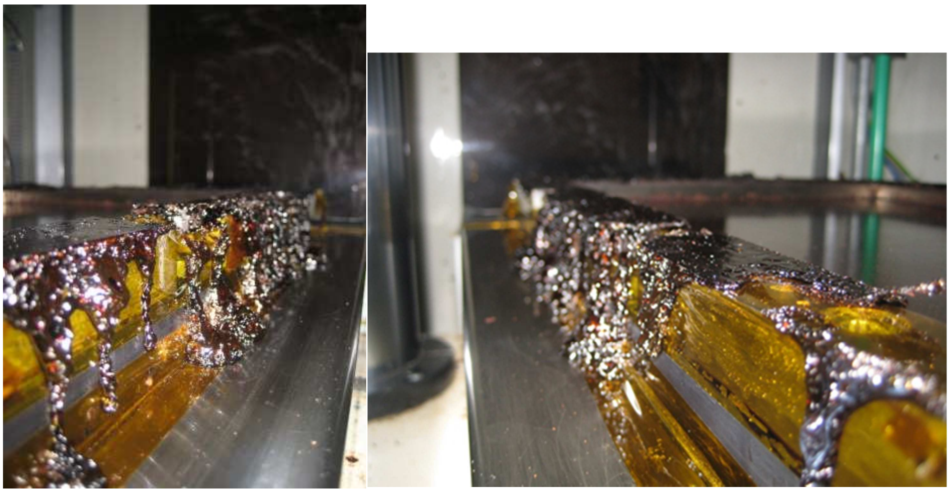

Figure 7 - Resin escape

For the next trials the fibre weight fractions were increased for flax prepregs to 54 % and for jute prepregs to 38 %. This led to better processability (see Figure 8~~Figure 8~~).

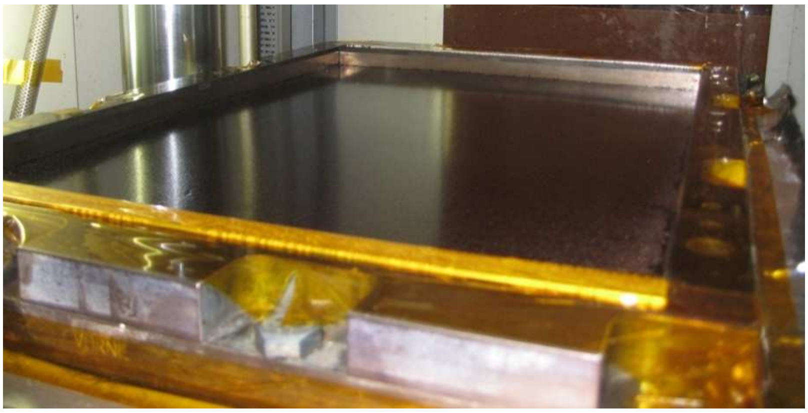

Figure 8 - Processing of natural fibre furan composites with higher fibre weight fraction.

For the production of sandwiches cork composites NL20 was used as core material with flax prepregs as layers. Using the same process parameters as for the panels without core leads to baggy sandwich panels and large enclosed gas blisters (see Figure 9~~Figure 9~~).

Figure 9 - Baggy cork sandwich panel

Therefore the process parameters were optimized for the production of sandwich panels with cork core. The panels have to be cooled under pressure (see Figure 10~~Figure 10~~), which leads to very good sandwiches with smooth surface (see Figure 11~~Figure 11~~).

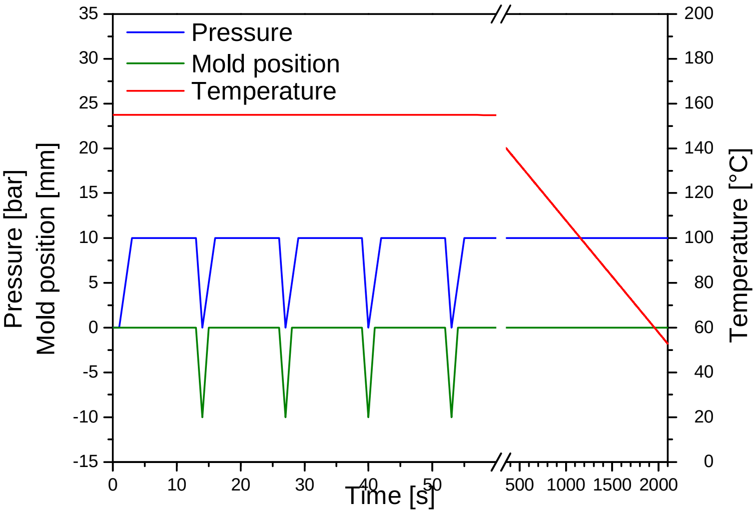

Figure 10 - Process parameters for the production of cork sandwich panels

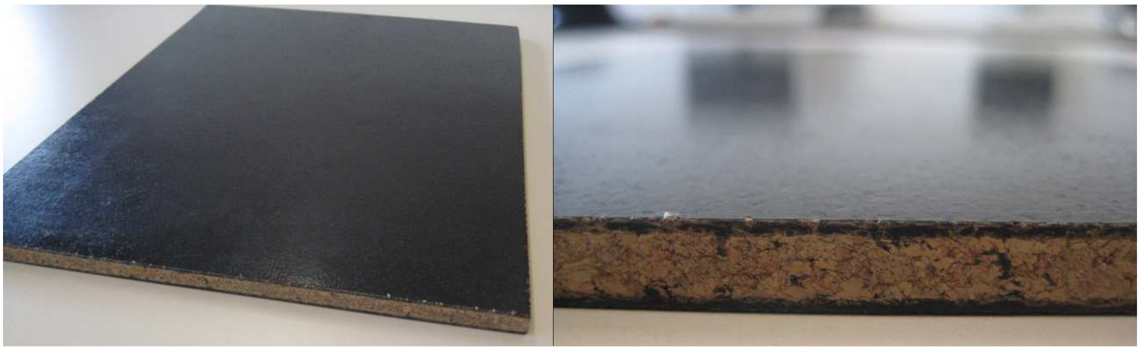

Figure 11 - Cork sandwich panels

4.2.2.2 Large scale – semi-continuous compression moulding

Attempts were made to transmit the small scale process parameters on large scale at the semi-continuous compression moulding machine. The same temperature and pressure course was used by producing panels and sandwich profiles.
The surface quality of the produced hat profiles was very good, but a lot of water could be observed, which could not evaporate through the metal release sheet (see Figure 12~~Figure 12~~). This water had a negative impact on the processing of endless sandwich panels with cork core. The cork absorbs water during the compression process which leads to insufficient cork/prepreg adhesion (see Figure 13~~Figure 13~~).

Figure 12 - Production of hat profile in the CCMM

Figure 13 - Bad adhesion between cork and prepregs

4.2.3 Optimised Bio-Pultrusion (Task 4.4)

This task represents an essential part of the project focused on the manufacturing of pultruded biocomposite parts, more specifically suspended ceiling panels. It was expected that the processing parameters and techniques would be different from the current practice because of the complex fibre feed systems required for precise fibre placement and, in the case of furan resin, the moisture due to the polycondensation reaction.

Most of the traditional resins used for composite materials can be used in pultrusion, although many are modified to meet the particular requirements of pultrusion. By far the most commonly used resins are unsaturated polyesters and vinyl esters, both usually employing styrene as the solvent/crosslinker. However, one of the objectives of this project is to use furan resin and bio-epoxy resin systems together with flax and jute fibres and continuous yarn, mat and textile formats in order to replace glass fibre in composite manufacture minimizing the environmental impact and the carbon footprint of the composite material.

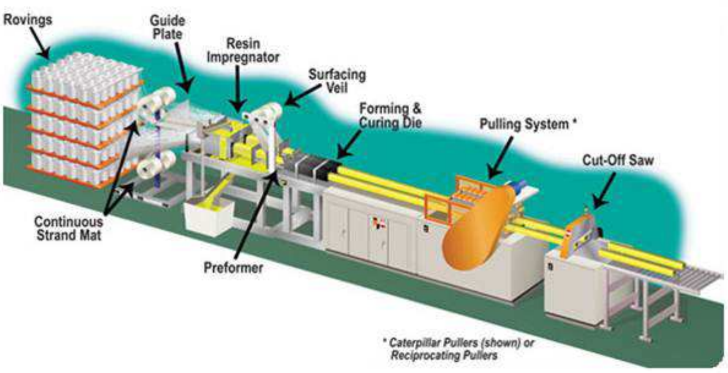

Figure 14 - Pultrusion machine scheme, Source: Strongwell.

4.2.3.1 Processing with furan

However, because of the processing difficulties of the pultrusion itself, starting the tests with both new resin and new fibre at the same time would likely lead to unpredictable results. For this reason it was more appropriate to proceed with a cautious plan of action, increasing complexity step by step. Glass fibre was used as reinforcement for furan resin as an interim stage, before using natural fibre. Figure 15~~Figure 15~~ corresponds to the pultrusion of furan resin with glass fibre and helps to illustrate the different steps of the pultrusion process: fibre wetting, fibre guiding, pass through the heating die and cutting to the desired length.

Figure 15 - Pultrusion with furan resin and glass fibre

The main conclusion drawn from the processing of furan resin and glass fibres can be summarised as follows:

- Furan resins have a very low reactivity which means that pultrusion speeds will be very low making the process not economically viable from an industrial point of view.
- The resins cure with an acid catalyst, and at the high processing temperatures needed produce fibre degradation and corrosion on the steel parts. The action of acids can cause hydrolysis in cellulose chains and other binding materials, thereby degrading the fibre bundle mechanical properties.
- It was therefore evident that this furan resin was unsuitable for use with natural fibres due to the acidic catalyst used to cure it.

4.2.3.2 Processing with bio-polyester

Once it was demonstrated that pultrusion with furan resin and glass fibre seemed not to be the most appropriate combination, the next option was to use bio-polyester resins in combination with flax fibres. Two resins were initially selected together with the following roving/fabric combination. With this combination the amount of flax roving is minimized and consequently the final cost of the pultruded profile (Figure 16~~Figure 16~~).

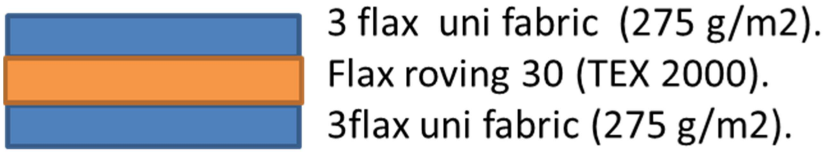

Figure 16 - Fabric combination for bio-polyester pultrusion

The first set of tests have already started and Figure 17~~Figure 17~~ shows the pultrusion process of bio-polyester resin and flax fibre.

Figure 17 - Pultrusion process with bio-polyester and flax fibre.

The pultrusion speed selected was 26 cm/min. After a few trials, the process parameters presented at Table 8~~Table 8~~ were selected.

Table 8 – Pultrusion parameters

Resin	Heating Zona 1	Heating Zona 2
Palapreg P17-02	120	150
Polres 106/BV BIO	150	180
Synolite ZW 7483	150	180

From the processing point of view first results can be summarized as follows:

- Processing of bio polyester is very similar to traditional resins: no big differences regarding pultrusion speed, heating temperatures and resin stability.
- Main drawbacks came from the natural fibre side. Dry natural fibres seem to have higher friction resistance than glass fibre, this produces fibre buckling, fibre rupture and fibre blockage near and in the mould.
- In order to solve this issues zinc stearate was added to the formulation and better results were obtained. More tests are underway to determine the proper additive concentration.
- In principle this seems to be the best option in order to manufacture pultruded profiles with natural fibres and bio-resins.

4.3 Summarized results

4.3.1 RTM/ Hand Lay-up/Vacuum Bagged Panels (Task 4.1)

Vacuum bagging processing of jute textile/flax mat lamellaes is essentially the same process; a little bit more time consuming because of the flax mat cutting step and proper positioning of all the components. A huge advantage is the excellent processing properties of biopolyester compared to furan resins and the fact that the finished part is almost 100 % biobased. One disadvantage that should be noted here is that no fire retardant is used unless large amounts of additives are added or FR topcoats applied. The mechanical performance of the produced lamellae is shown in the Table 9~~Table 9~~.

Table 9 - Mechanical performance of the produced lamellae

				Flexural Properties	
Skin	**Core**	**Fibre orientation**	**Thickness (mm)**	**Strength (MPa)**	**Modulus (MPa)**
Jute twill	Cork	0/90	4.5	55.6	3335
Jute twill	Cork	-45/+45	4.5	44.4	2444
Jute twill	1 - flax mat	0/90	3.3	97.53	3988
Jute twill	1 - flax mat	-45/+45	3.3	72.33	2638
Jute twill	2 - flax mat	0/90	4.4	85.69	4239
Jute twill	2 - flax mat	-45/+45	4.4	72.36	2794
Jute twill	3 - flax mat	0/90	5.5	87.87	4679
Jute twill	3 - flax mat	-45/+45	5.5	82.69	3596
Pultruded profile		UD (Flax)	2.8	215	22000 - 23000

4.3.2 Semi-Continuous Compression Moulding Process (Task 4.3)

Test specimens obtained by this process were tested. The results are presented in section 6.3.2.

4.3.3 Optimised Bio-Pultrusion (Task 4.4)

4.3.3.1 Tensile tests

Tensile tests performed on both glass/furan and glass/polyester laminates showed comparable properties (tensile modulus), see Figure 18~~Figure 18~~ and Figure 19~~Figure 19~~. In the case of tensile strength, glass/furan outperformed the reference material, if the lowest pultrusion speed was used (P1). Postcuring step seems to do not have any effect on mechanical properties and do not produce any improvement in either exterior appearance or properties.

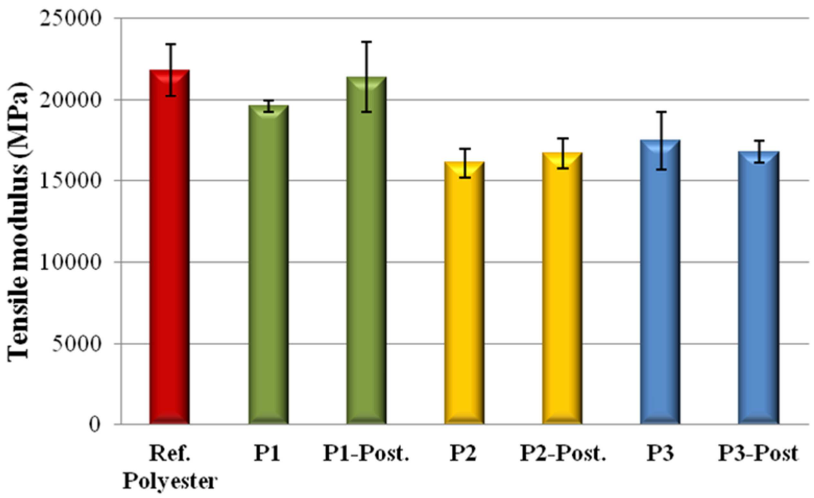

Figure 18 - Tensile modulus of pultruded profiles, furan resin + glass fibre

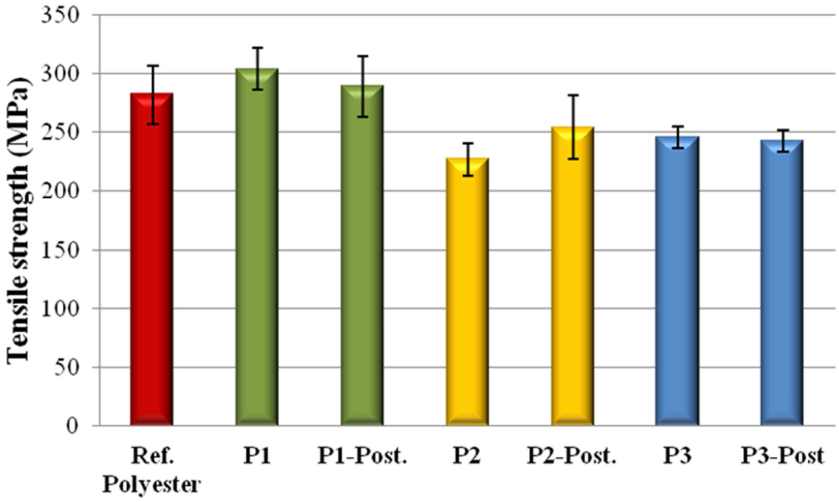

Figure 19 - Tensile strength of pultruded profiles, furan resin + glass fibre

4.3.3.2 Flexural tests

Figure 20~~Figure 20~~ and Figure 21~~Figure 21~~ show the flexural modulus and strength of the materials tested. In all cases poor results were seen in the laminates using furan resin compared with the reference panels using polyester resin. A reduction on flexural modulus and strength of up to 60% and 70% respectively are observed.

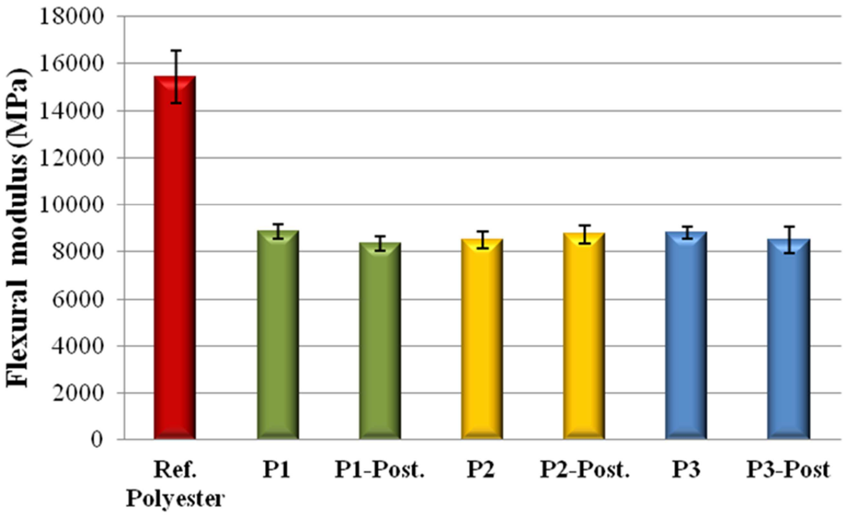

Figure 20 - Flexural modulus of pultruded profiles, furan resin + glass fibre

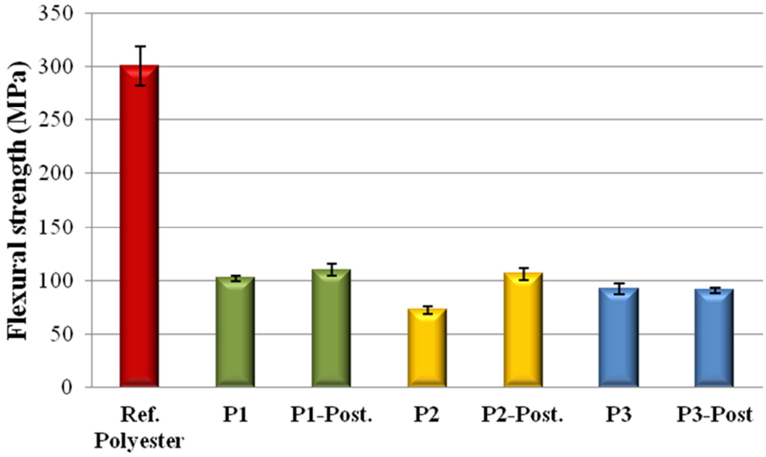

Figure 21 - Flexural strength of pultruded profiles, furan resin + glass fibre

Main conclusions drawn from mechanical testing are summarized below:

- Furan resins contains different amounts of water which, in conjunction with the water produced during the curing reaction, leads to pultruded profile with high void content and as a result poor mechanical properties.
- In general low viscosity furan resins contain more water and lead to more porous composite materials with lower mechanical performance.
- Furan resins with lower water content have higher viscosities, which prevent a good impregnation of reinforcing fibres and consequently produce pultruded panels with poor mechanical properties.
- The third option is to select furan resins with higher reactivity, but even if this will have a positive effect on pultrusion speed (higher) it would decrease pot life and make very difficult to work with it. Obviously, lower reactivity lead to lower pultrusion speed and larger pot life but from an industrial point of view the process seems not to be economically viable.

4.3.3.3 Fibre volume percentage

The results of fibre volume percentage measurements are summarised in the Table 10~~Table 10~~.

Table 10 - Fiber volume percentage measurements

	Fibre volume (cm^3)	**Resin volume (cm^3)**	**Fibre (% vol)**	**Resin (% vol)**
Perfil Palapreg	165,58	239,55	40,87	59,13
Perfil Polres	165,58	221,05	42,83	57,17
Perfil Synolite	165,58	188,7	46,73	53,27

Fibre content lies between 40 and 47 %, which is too low compared to pultruded profiles with glass fibre. Flax fibre has excellent specific properties, this means dividing their properties by their density, but to reach similar performance to glass fibre pultruded profiles dimensions of the profile have to be increased in order to incorporate more fibre.

4.4 Ongoing work / Difficulties / Additional work still to be done

4.4.1 RTM/ Hand Lay-up/Vacuum Bagged Panels (Task 4.1)

- Selection of the more adequate combination, taking into account both mechanical requirements and aesthetics.
- Combine pultrusion of biopolyester, flax and cork.

4.4.2 Semi-Continuous Compression Moulding Process (Task 4.3)

- More trials with the CCMM in order to imitate the static press results.
- Using another, more permeable textile in the prepreg and another, more permeable release sheet during next trials.

4.4.3 Optimised Bio-Pultrusion (Task 4.4)

- Continue with pultrusion of bio-polyester and flax.
- Combine pultrusion of biopolyester flax + cork.
- Comparison in between flax and glass fibres in pultrusion with biopolyester resin.

5 WP5 Construction system integration

5.1 Concept and design development

The BioBuild project entails the design and construction of four case studies. These refer to both external and internal systems and specifically: an External Wall Panel (EWP), an External Cladding Kit (EKC), an Internal Partition Kit (IPK) and a Suspended Ceiling Kit (SCK).

All systems have been assessed on specific criteria, including fire-safety; dimensional stability; in-service resistance to loads; thermal and acoustic insulation; energy efficiency; and sustainability.

The first case study, the EWP, is a façade panel incorporating insulation and window elements, with the purpose of separating the outdoor climate from the indoor climate. It is self-supporting with an internal structure and is designed to resist wind loads and impacts. The panel does not perform any structural purpose in relation to the building and it is conceived to be applied in a unitized façade system. Potential problems (such as the spread of fire from one floor to another; and the permeation of sound from one room to another) have been assessed at the EWP's connection to the floor slab and perimetral walls. Technical solutions have been adopted to solve these issues and at the same time to overcome the in-service deflections at the floor slab. Thermal-insulation performance has influenced the design by defining the potential thickness of the EWP. The formal-design process considered both a flat panel, and a three-dimensional shape allowing the window elements to be shaded by the composite element. The on-site handling of such large, fully fabricated elements has also been one of the major design drivers for the EWP. Therefore, design effort was focused on panel-to-panel and panel-to-building interfaces, to ensure a tight seal to protect against the outside environment.

The second case study, the ECK, is a rain-screen system comprised of plates or panels, with the purpose of protecting the wall (insulation, structure, etc.) behind it from water and driving rain. The external cladding is also an important architectural element as it is the outermost layer of the building façade. The design process has been focusing on incorporating elements that would ensure that the panels have the desired flatness, and on connection details to ensure a smooth panel-to-panel transition. For these reasons, the edges of the system have been designed to maximise resistance to weather. Consideration has also been given to the method of connecting the panel to the substructure, to ensure that the panels can be installed efficiently and that the tolerances of the construction can be accommodated in the connection design.

The third case study, the IPK, is a flat, vertical system that can perform as a functional separator between two rooms. The IPK design process has three main drivers: fire performance, acoustic performance, and ease of installation. Fire performance is probably the most critical driver, as the panel will be used for internal applications. Special attention has to be given to panel-to- structure connections, and when considering the panel-to-floor/ceiling interface. As the IPK will act as a functional separator, acoustics are also an important part of the design. This not only relates to the acoustic-dampening effect of the panel but also to connections with external parts (floor, ceiling and walls) and internal parts (between panels, structure and fixings). Detailing around floor and ceiling connections has also been designed to minimize the risk of transmission of vibrations from one side of the panel to the other caused by direct connections between the panels' internal support structure. It is also important that the installation of the IPK is easy for the system to be commercially viable, as installation time is often critical to the completion of a building. The idea for optimising the ease of installation is to minimise the number of components used in the IPK, and to reduce the number of steps needed to install the system.

The fourth system, the SCK, is an open, lamella-based element attached to a structural grid. The SCK acts as an architectural element with the purpose of hiding technical installations in the gap between the lamellae and the building floor plate. The design process has been influenced by a number of parameters, including acoustic performance, fire performance and architectural expression. To ensure a good working environment in buildings, suspended ceilings often incorporate surfaces with large sound-absorption coefficients. This has been a main design driver for the SCK, and the potential increase in absorption area provided by the lamellae has resulted in the system being chosen over flat, horizontal panels. The effectiveness of the SCK system can be increased by including an acoustic insulation layer attached to the exposed part of the floor slab. The system is also conceived to be adaptable. For example, it should be possible to include lighting systems between the lamellae. The designed system therefore consists of simple parts that can be attached in any location allowing the system to be configured differently.

5.2 Production process selection

The four design systems have been designed according to the most suitable production process and according to the manufacturing capabilities existing within the consortium.

The EWP system is going to be built mainly by using a hand lamination process, while some parts will be produced through the vacuum infusion and closed moulding processes. The EWP should be mainly composed of jute or flax fibres and bio-polyester matrix in the case of hand lamination and vacuum infusion instead the matrix could be furan in case of flat moulded sheets used as the internal facing layer (this is mainly due to the better fire performance showed by the furan that would increase the fire properties of the internal surface of the panels). Since the design of the EWP is still ongoing at present stage future changes and modifications regarding both the production process and the materials can happen.

The composite considered in the case of the ECK system are going to be produced using the semi-continuous moulding process for both the “open-hat” profile, acting as back structure, and the flat cladding panel fixed to them.

The IPK system will be produced using the double press technology for the large flat surfaces using mainly flax fibres and furan resin. In the case of the IPK it has been clearly pointed out the need for a supporting system to be included in the air gap in between the two flat surfaces of the wall panels; in this case the choice of the consortium has been directed to the use of hybrid pultruded L profiles.

In conclusion, the production process for the lamellae to be included within the SCK could be either vacuum infusion or semi-continuous moulding. The supporting structure to which the lamellae are mechanically fixed would be composed of hybrid pultruded profiles.

5.3 Adhesive selection

Adhesive selection has been carried on considering both the compatibility of the materials and the structural performance needed for the systems (including the elongation at break of the adhesive). The following adhesives have been chosen:

- Macroplast UK 8326 B30. This adhesive is a 2K polyurethane currently used by Fiber-Tech for GFRP systems
- SikaFast 5221. This is a 2K acrylic adhesive. It has a high elongation at break and a lower tensile-shear strength respect to the previous one
- SikaForce 7710 L100

The adhesives are currently being investigated to assess the mechanical performance once combined with the biocomposite substrate.

5.4 Coating selection

This selection of the coating layers has been coordinated together with WP3. A list of potential coating options is reported in the Table 11~~Table 11~~.

Table 11 - Potential coating options

Type	Suggested use	Coating thickness	Expected durability	Expected fire behaviour
Free film polyester foil coating	External	≈300µm	High	n/a
Low-bake Powder coating	External	70µm-1000µm	High	n/a
2K Water based polyurethane	External/Internal	300µm-800µm	Medium	Depending on the formulation
2K Solvent borne polyurethane	External/ Internal	300µm-800µm	Medium	Depending on the formulation
One component Alkyd	Internal	120µm-180µm	Low	Depending on the formulation

The coatings are available in different colors and as transparent layers. SHR is currently in the process of preparing the substrate materials to which apply the different coating types. The specimens will be then tested both for durability performance (SHR) and for fire performance (LNEC). Looking at the general features, it is possible to firstly guess which coating type is more suitable for the different systems, as reported in Table 12~~Table 12~~.

Due to poor reaction to fire performance of it was decided to select an intumescent coating for bio composites to apply on samples to be submitted to SBI test. The selection was made having in mind the following considerations:

- Test results are always based on the intumescent (fire retardant) coating on a substrate and the choice of substrate has large impact on the results.
- Most of the offered intumescent coating systems are designed for interior use.
- Intumescent coatings by themselves have bad weathering behaviour because of the fire retarding additives which increase the porosity and water uptake.

- By using a top-coating (on top of the base coat/intumescent coating) the aesthetics and the weather ability can be improved.
- 2K systems give the best results with respect to weathering resistance. The harder component in the 2 K systems normally determines the weather resistance. An aliphatic harder system offers the best properties regarding weathering compared to the aromatic harder systems (which are cheaper).
- We have to be aware that a top coating can have a negative influence on the fire retarding result in the SBI test
- The best top-coatings for this purpose have to be selected based on low caloric value of these top-coatings.

Based on these considerations, a transparent fire retardant coating (internal application) was selected. This corresponds with product “TE Clear waterborne fire-retardant system” of Sayerlack (400 gr/m^2).

The edges of a sandwich board are a potential weak spot which can have a major effect on the results of the reaction to fire test. The edge of a sandwich board is not easily sealed with a relative thin layer of coating, but need some extra pre-sealing. It was suggested the edges of these boards to be pre-sealed with a (preferably fire retardant) sealant which can be over coated. Then the selected fire retardant coating system shall be applied over the sealed edges. It is even advisable to give the edges an extra layer of fire retardant coating (so 3 layers instead of 2).

Table 12 – Coating options for kits

System	Possible coating options associated
EWP (External Wall Panel)	Free film polyester foil coatings Low-bake Powder coatings
ECK (External Cladding Kit)	Free film polyester foil coatings Low-bake Powder coatings
IPW (Internal Partition Wall)	2K Water based polyurethane 2K Solvent borne polyurethane
SCK (Suspended Ceiling Kit)	2K Water based polyurethane 2K Solvent borne polyurethane

5.5 Insulation selection

Selection of the most suitable insulation material has been carried on considering the following main drivers:

- High acoustic insulation values
- Low embodied energy
- Low thermal conductivity

Table 13~~Table 13~~ reports a list of insulation materials and their main physical performance.

Table 13 – Insulation materials

Type	Density (kg/m3)	Embodied energy (MJ/kg)	Thermal conductivity (W/m°K)	Cost (€/m2) 5 cm thick
Rockwool	60	20.2	0.031–0.040	3-5
Glasswool	50	45.5	0.031–0.040	3-5
Flax insulation sheet	28	15.5	0.038–0.040	10-12
Jute insulation sheet	28	13.2	0.038–0.040	8-10
Foamed cork	120	28.0	0.038-0.050	5-7
Sheep wool	40	45.1	0.039	11-14
Cellulose from waste paper	70	20.5	0.038-0.040	3-5
Wood wool	100	13.6	0.038	12-16
Poly Lactic acid foam	35	64.3	0.035	5-7

The consortium has decided to proceed with the use of Rockwool as insulation material for the SBI test and looks forward for the selection of a different insulation material for the full scale systems. It should be pointed out that even though the Rockwool option does not have the lowest embodied energy value, it surely represents an optimal compromise once considered all the different aspects, cost, EE and thermal conductivity.

5.6 Sealant selection

Sealants have been chosen considering the compatibility with the biocomposite materials and also their capacity to fill the gaps amongst components and adapting to variable tolerances. A list of options is following reported:

- Dow Corning 791, silicone weatherproofing sealant
- Bostik Intucrylic, acrylic intumescent sealant
- PFC Corofil, acoustic intumescent sealant
- Rockwool Firepro, acoustic intumescent sealant

Looking at the general features of the sealant options it is possible to define which type is more suitable for the different systems, as reported in Table 14~~Table 14~~.

Table 14 - Coating options for kits

System	Possible coating options associated
EWP (External Wall Panel)	Dow Corning 791
ECK (External Cladding Kit)	Dow Corning 791
IPW (Internal Partition Wall)	Bostik Intucrylic PFC Corofil Rockwool Firepro
SCK (Suspended Ceiling Kit)	Bostik Intucrylic PFC Corofil Rockwool Firepro

Fire behaviour of the sealants once applied to the systems can be obtained after the SBI test. Durability tests for the product should be performed as well in WP3.

6 WP6 Evaluation of Biocomposite System Performance

6.1 General

Work Package 6 started at May of 2013 (M18) and is subdivided in three subtasks, namely "6.1 - Testing of Lab-Scale Systems", "6.2 Manufacture of Full-Size Systems" and "6.3 Testing of Full-Size Systems". The ongoing work has been developed mainly in the aim of sub task 6.1, which is expected to finish by the end of May 2014. Task 6.1 includes the subtasks "6.1.1 - Specification, design and manufacture of Lab-Scale Systems" and "6.1.2 - Testing of Lab-Scale Systems". The work carried out in these two subtasks is reported here and is the contribution of WP6 to the assessment of the feasibility of the biocomposite systems, designs and installations. To contribute to this assessment, the tests, that have been carried out with the purpose of providing a fast evaluation of key properties of materials or combination of materials to help deciding if they are adequate to be used in Biobuild products, are also presented here.

6.2 Sub-Task 6.1.1 Specification, design and manufacture of Lab-Scale Systems

The test specimens that are produced for testing in sub-task 6.1.2 consist of material combinations (see WP3 Task 3.5), assemblies of panels, profiles and fixings (see WP4 Task 4.6), and small-scale demonstration units (see WP5 Task 5.3). This set of tests includes small tests on materials or material combinations in order to have their basic performance to better understand the test behaviour of assemblies. In Table 15~~Table 15~~ these tests are listed and the number and quantity of samples is presented.

The following systems/material combinations (for all applications) have been identified:

- A: Resin + reinforcement (fibre);
- B: Resin + reinforcement (fibre) + core;
- C: Resin + reinforcement (fibre) + core + coating;
- D: Resin;
- E: Composite profiles;
- F: Core.

In Table 15~~Table 15~~ the tests that are relevant for every system/material combinations are indicated. The tests shall be repeated on different system/material combinations and even for the same materials if there is strong anisotropy on reinforcement (fibres). Different partners have been involved in the manufacture and supply of test samples. In Table 16~~Table 16~~ the allocation of tasks of the partners relating to the supply of test samples is presented.

Table 15 – Tests on materials and on material combinations

Test	Method	Samples	Quantity	Partner(s)	Type	Comments/type of testing sample	
Determination of dynamic mechanical properties (storage modulus, loss modulus and tan delta) during a linear temperature scan under heating conditions	ISO 6721	Length 60 mm Width 15 mm Thickness 4 mm	≥ 10 test specimens per material	LNEC/NMO	Performance	A	E
Determination of flexural properties at ambient temperature	EN ISO 14125 ISO 178	Preferred dimensions: Length (l) 80 mm Width (w)10 mm Thickness (h) 4 mm	≥ 12 test specimens per material	LNEC/NMO	Performance	ETAG 034 (EN ISO 178) Other dimensions are possible (Table 2 of ISO 178 and table 3 of ISO 14125): 1<h≤50; 10<h≤50; l=f(L) L≈16h	
						A, C	E
Determination of tensile properties at ambient and at elevated temperatures	EN ISO 527-1,4	Length 250 mm Width max 50 mm Thickness 4 mm	≥ 10 test specimens per material	LNEC/NMO	Performance	A, C	E
Charpy impact properties or Izod impact strength or tensile impact strength	EN ISO 179-1 EN ISO 180 ISO 8256	Preferred dimensions: Length (l) 80 mm Width (w)10 mm Thickness (h) 4 mm	≥ 10 test specimens per material	LNEC/NMO	Performance	The impact method should be selected according specimen characteristics Other dimensions are possible (Table 1 of ISO 179 and table 2 of ISO 8256)	
						A, C	E
Temperature of deflection under load	ISO 75-3	Length 80 mm Width 10 mm Thickness 4 mm	≥ 2 test specimens per material	LNEC/NMO	Performance	A	E

Test	Method	Samples	Quantity	Partner(s)	Type	Comments/type of testing sample	
Water vapour permeability	EN 12086 EN ISO 12572 (alternative)	≥ 500 cm^2 or (Length 200 mm Width 200 mm Thickness 4 mm)	≥ 5 test specimens per material	LNEC/NMO	Performance	ETAG 003 B, C	E
Determination of water absorption properties under controlled conditions at ambient and elevated temperatures	EN ISO 62	Length 100 mm Width 100 mm Thickness 4 mm	≥ 3 test specimens per material	LNEC/NMO	Performance	A, B, C	E
Volatile Organic Compounds (VOCs) emissions from Building materials	ISO 16000-3,6 EN 717-1	Length 200 mm Width 280 mm Thickness any	2 per system (panels)	LNEC/NMO	Performance	ISO 16000-9 is general for building materials. EN 717-1 is only for formaldehyde emission. A, B, C, D	-
Thermogravimetry	ISO 11358	Small pieces (≤50 mg) extracted from other specimens	2	LNEC/NMO	Identification tests	C (extraction of different parts from other specimens)	E
Density or mass/unit area as appropriate	EN ISO 10352 EN ISO 1183-1	Density: small pieces extracted from other specimens	≥ 12 test specimens per material	LNEC/NMO	Identification tests	ETAG 034 (EN ISO 1183-1) A, B	E
FTIR spectroscopy		small pieces extracted from other specimens	≥ 2	LNEC/NMO	Identification tests	C (extraction of different parts from other specimens)	E
Climatic testing cycles	ETAG 016	Length 500 mm Width 500 mm	≥ 12 x 5	LNEC	Durability	ETAG 034 (ISO 877) water absorption, DMA, compressive, tensile, and	

Test	Method	Samples	Quantity	Partner(s)	Type	Comments/type of testing sample	
						impact properties after ageing	
Exposure to solar radiation	ISO 877-1 ISO 4582	for colour: Length 150 mm Width 70 mm Thickness any	3 (for colour)	LNEC/NMO	Durability	B, C	E
Dimensional stability at ambient and elevated temperature	EN 438-2 Sections 17 & 18	Length 250 mm Width 50 mm Thickness of laminate	16	LNEC/NMO	Durability	ETAG 034 5.7.2 Part 1 B, C	E
Resistance to deterioration Chemical agents	Cleaning products EN ISO 26987 (ex EN 423)	Length 200 mm Width 280 mm Thickness any	1	LNEC/NMO	Durability	ETAG 003 C	
Measurement of changes in colour and variations in properties after exposure	(according the property to be measured)	The same samples indicated previously for exposure testing	-	LNEC/NMO	Performance	B, C	E
Measurement of gloss	EN ISO 2813	The same samples indicated previously for exposure testing	-	LNEC/NMO	Performance	B, C	E
Ignitability test	EN ISO 11 925-2	250 mm x 90 mm x thickness	6	LNEC/NRI	Performance	A, B, C, D, E, F	
Determination of moisture resistance under cyclic test conditions	EN 321 EN 310	50 x 50 x real thickness	12 samples Resin + reinforcement	LNEC/NCE	Durability	ETAG 034 A	
Durability of wood and wood-based products. Determination of the natural durability of solid wood against wood-destroying fungi, test methods. Part 1: Basidiomycetes	DD 15083-1 (replaces EN 113)	(5 × 10 × 100)mm	30	LNEC/NCE	Durability	C, F	
Durability of wood and wood-based products — Determination of the natural durability of solid wood against wood-destroying fungi, test methods — Part 2: Soft rotting	DD 15083-2	5 × 10 × 100	30	LNEC/NCE	Durability	C, F	

Test	Method	Samples	Quantity	Partner(s)	Type	Comments/type of testing sample
micro-fungi						
Standard Test Method for Determining Fungi Resistance of Insulation Materials and Facings Plastics - Assessment of the effectiveness of fungistatic compounds in plastics formulations	ISO 16869	10 mm (thickness) x 40 mm (diameter)	3	LNEC/NCE	Durability	C, F
Biological resistance - plastics	EN ISO 846	2 mm × (30-60)mm × (30-60) mm	15 specimens per sample and per test method	LNEC/NCE	Durability	ETAG 034 Methods A and B only. Possible alternative to this method - ASTM C1338 (2008) Standard test method for determining fungi resistance of insulation materials and facings. C, F

Test	Method	Samples	Quantity	Partner(s)	Observations	Comments
Resistance to immersion in boiling water	EN 438-2 Section 12			SHR	Performance	Tests conducted after material production
Resistance to wet conditions (exterior grade laminates)	EN 438-2 Section 15			SHR	Performance	
Resistance to climatic shocks (exterior grade laminates)	EN 438-2 Section 19			SHR	Performance	
Strength	ISO 178			SHR	Performance	
Resistance against UV light	EN 438-2 Section 28			SHR	Durability	After the ageing procedures deformation and surface quality will be assessed. Also, the tests resistance to immersion in boiling water, strength and resistance to climatic shocks will be performed.
Resistance against fungi decay	ENV 12038			SHR	Durability	

Table 16 – Request of test samples

Partner	D: Resin	F: core	A: Resin + reinforcement (fibre)	B: Resin + reinforcement (fibre) + core	C: Resin + reinforcement (fibre) + core + coating	E: Composite profiles
TFC	IPK, ECK, SCK (1)					
Net Composites			IPK, ECK, SCK (2)			
Amorim		IPK, ECK, SCK (3)		IPK (4)	IPK (5)	
EXEL						IPK, ECK (6)
IVW				ECK (7)	ECK (8)	
ACCIONA				SCK (9)		
Fiber-tech				SCK(10)	SCK (11)	

IPK – Internal Partition Kits
ECK – External Cladding Kits
SCK – Suspended Ceiling Kits

The specification of Full-Size Systems (that will be manufactured in the aim of task 6.2 and tested in the aim of task 6.3) was already carried out and is presented in the annex A to D. This specification needs to be updated according to the test results and conclusions obtained from lab-scale tests.

The specification and design of the above test specimens was made according to the outputs from WP1.

ARUP, in contact with LNEC, prepared the specification of test specimens for the Single Burning Item reaction to fire test. Individual specifications have been prepared for the Biobuild products and they are presented in annex E for ECK, in annex F for IPK and in annex G for SCK.

6.3 Sub-Task 6.1.2 Testing of Lab-Scale Systems

Two sets of test samples have been received. The first set of test samples was provided in order to assess the performance of the materials to assist to the development of Biobuild products. These tests were used to support the choice of materials before the full development of the Biobuild products. The purpose of these tests was:

a. To assess basic performance of materials
b. Tests to assist the selection of coatings

The second set of tests has been carried out in order to comply with the Lab Scale Test plan (see Table 16~~Table 16~~). The samples received correspond to the positions 2, 3, 6, 7 and 9. Finally, test samples for screening SBI tests have been developed.

In the next sections the test results already obtained and the corresponding conclusions are presented. In section 6.3.1 the assessment of the basic performance of the materials is presented. The assessment of the mechanical performance of samples 2, 6 and 7 (see Table 16~~Table 16~~) are presented in the section 6.3.2. The determination of the reaction to fire performance is presented in section 6.3.3.

6.3.1 Assessment of basic performance of materials

6.3.1.1 Materials

In Table 17~~Table 17~~ materials of the samples tests for the assessment of basic performance of materials are presented.

Table 17 – Assessment of basic performance of materials

Test	**Date (reception)**	**Material**
VOC	April	furan-flax prepreg
Fungi resistance	April	furan-flax prepreg
Thermal conductivity	2013-07-09	2 x Compression-moulded [4x prepreg-10mm cork-4x prepreg] sandwiches
Thermal conductivity	2013-07-09	2 x Vacuum-bagged [3x prepreg-10mm cork-3x prepreg] sandwiches
Sound absorption	2013-07-09	Product C - 2 x Compression-moulded [4x prepreg-10mm cork-4x prepreg] sandwiches
Sound absorption	2013-07-09	Product V - 2 x Vacuum-bagged [3x prepreg-10mm cork-3x prepreg] sandwiches

6.3.1.2 Volatile organic compounds

A qualitative analysis of organic compounds emitted from a sample of furan-flax prepreg was made in order to assess the potential emission of Volatile Organic Compounds (VOC). Solid-Phase Microextraction (SPME) sampling was used and the analysis was carried out with Gas Chromatography – Mass Spectrometry (GC-MS). The identification of the compounds was made by matching the obtained mass spectra with commercially available compilations of mass spectra. The following suggestions of Volatile Organic Compounds (VOC) and Semi Volatile Organic Compounds (SVOC), emitted from the sample at 50 ºC, were obtained from a mass spectra library:

- VOC
    - Furan compounds:
        - Furfural;
        - 2-Furanmethanol;
        - Tetrahidro-2-furanmethanol;
        - 5-methyl-2-furancarboxaldehyde
    - Other probable compounds:
        - alcohols and aromatics (probably toluene)
- SVOC
    - Propanoic acid, 2-methyl-, 1-(1,1-dimethylethyl)-2-methyl-1,3-propanediyl ester

6.3.1.3 Fungi resistance

Under the test conditions described in ASTM C1338-08 Standard Test Method for Determining Fungi Resistance of Insulation Materials and Facings, the tested specimens of "furan-flax prepreg" (n=6) did not show any resistance to the development of molds. Their behaviour was similar to the filter paper controls.

6.3.1.4 Thermal conductivity of agglomerated cork

The contribution of agglomerated composite cork as a thermal insulating core has been assessed. Preliminary tests have been performed either over:

- Sandwich panels (compression moulded and vacuum bagged) prepared by Netcomposites, with a 10 mm cork core supplied by AMORIM ACC;
- 12 mm agglomerated composite cork (AMORIM ACC) boards.

The results obtained in the sandwich panels were influenced by the small thickness of the cork core (10 mm) which became impregnated by the resin. Therefore the obtained lambda values (thermal conductivity) were uninterestingly high:

- **0,098** W/m.ºC, for the compression moulded specimens;
- **0,060** W/m.ºC , for the vacuum bagged specimens.

Lambda values (thermal conductivity) obtained in non-impregnated cork samples were much lower and can be positively compared with some thermal insulating bio-alternatives. Agglomerated composition cork Lambda values (**0,043** W/m.ºC) are only about 10% higher than other alternative bio or non-bio products (see Table 13~~Table 13~~). Other factors may influence the choice of the thermal insulation core. Nevertheless, in some case studies, namely if a thicker cork core/layer is used, its contribution to the overall thermal resistance must not be overlooked.

6.3.1.5 Sound absorption tests

The tests were performed using the Kundt Tube and two samples of each product (Figure 22~~Figure 22~~). Figure 23~~Figure 23~~ and Figure 24~~Figure 24~~ show some of the results obtained. They are presented in accordance with the sample used, including the frequency-dependent absorption coefficients for both exposed surfaces.

Figure 22 – Test samples dimensions

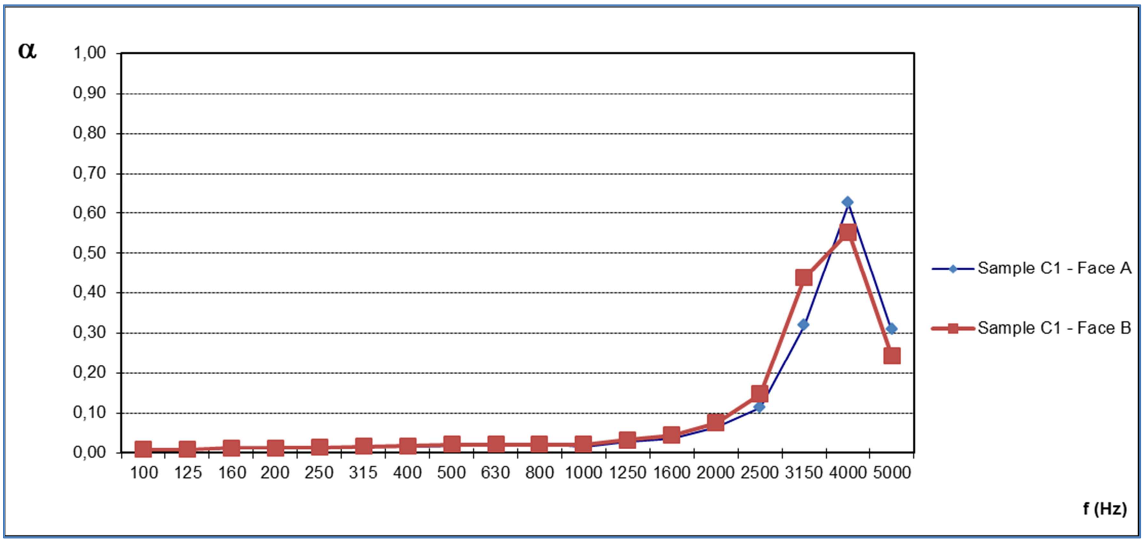

Figure 23 - Product C: Sample C1, Faces A and B

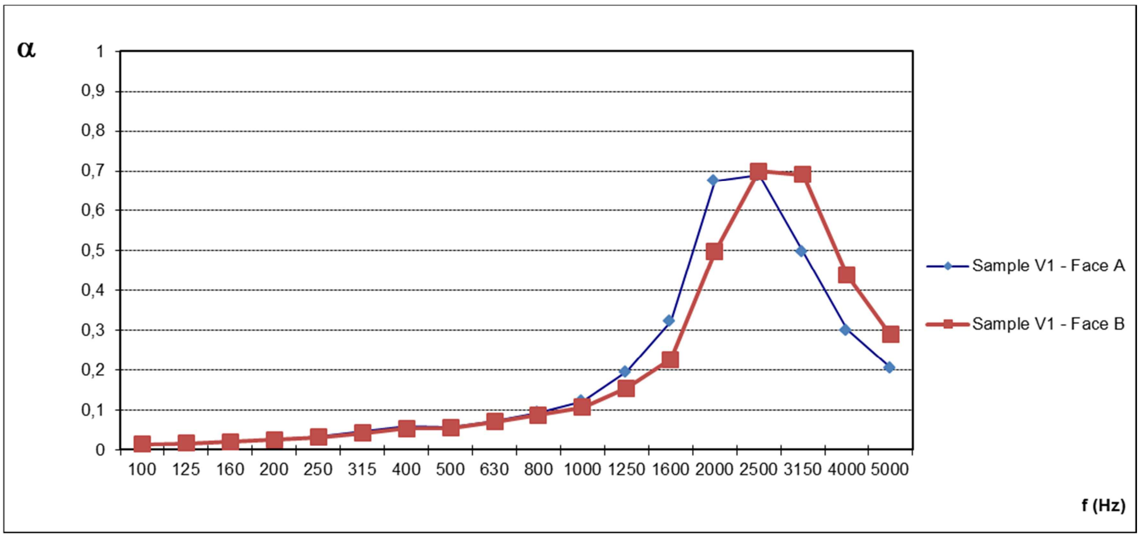

Figure 24 - Product V: Sample V1, Faces A and B

The tests performed show that the behaviour related to both products is similar in terms of absorption properties throughout the frequency range normally considered for construction materials.
It can be seen that both materials exhibit a fair performance in the high frequency range of the spectra, but very low absorption in its complementary part (the most important one for speech correction purposes). Notwithstanding that, the sound absorption of product V in high frequencies region is a little bit enlarged in frequency domain than that of product C. Additionally, it can be noticed that the "peak" of absorption for product V is displaced 2-3 bands towards low frequencies.
For practical reasons these tests are only suitable for comparison procedures between samples, not giving enough information, or being not strictly reliable, whenever dealing with practical applications in rooms, where the established noise fields are diffuse (random incidence).
Thus, in this context, it can be concluded that, if a more detailed analysis is intended, absorption tests in diffuse field should be done.

6.3.2 Assessment of mechanical performance

6.3.2.1 Samples

The following samples were tested:

- A: Resin + reinforcement (fibre) – 1 sample (compression-moulded flax+furan); samples 2 from Table 16~~Table 16~~;
- B: Resin + reinforcement (fibre) + core – 2 samples (lamella sandwich constituted by synolite ZW 7961 – UP - 0/90º jute 2x2 twill fabric on surfaces and cork in the core; flax/furan prepreg on surfaces and cork in the core); samples 7 from Table 16~~Table 16~~;
- E: Composite profiles (polyester resin - natural fibre mat on surfaces and unidirectional glass fibres in the core); samples 6 from Table 16~~Table 16~~.

Before testing, all specimens were conditioned in the testing room during a minimum period of 24 h, at (23 ± 2) ºC and (50 ± 5)% relative humidity. The mechanical tests were also performed at variable conditions, but respecting the previous environmental limits. Figure 25~~Figure 25~~, Figure 26~~Figure 26~~, Figure 27~~Figure 27~~ and Figure 28~~Figure 28~~ show a general view of the received samples:

Figure 25 - General appearance of a lamella sandwich constituted by synolite ZW 7961 – UP - 0/90º jute 2x2 twill fabric on surfaces and cork in the core (sample type B)

Figure 26 - General appearance of a composite constituted by polyester resin - natural fibre mat on surfaces and unidirectional glass fibres in the core (sample type E)

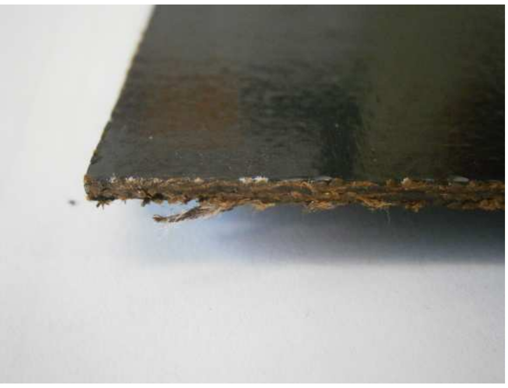

Figure 27 - General appearance a compression-moulded flax+furan (sample type A)

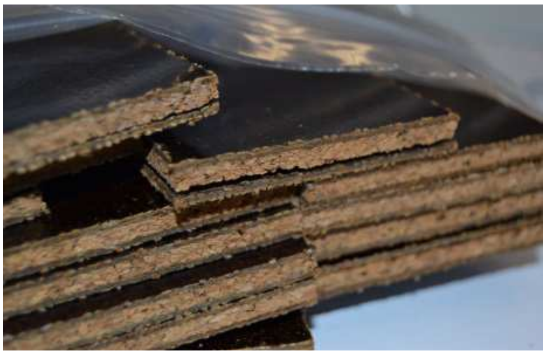

Figure 28 - General lateral appearance of a composite constituted by flax/furan prepreg on surfaces and cork in the core (sample type B)

6.3.2.2 Test conditions

The most relevant test conditions are summarized in Table 18~~Table 18~~, Table 19~~Table 19~~, Table 19~~Table 19~~ and Table 19~~Table 19~~. Figure 29~~Figure 29~~, Figure Figure 30~~Figure 30~~, Figure Figure 30~~Figure 30~~ and Figure Figure 30~~Figure 30~~ illustrate typical fixtures of the different mechanical tests performed.

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Table 18 - Tensile test conditions

Testing standard	ISO 527-4 (1997) - Plastics - Determination of tensile properties. Test conditions for isotropic and orthotropic fibre-reinforced plastic composites
Equipment:	universal testing machine INSTRON Model 4302
Load cell	10 kN with an accuracy grading of 0.5
Initial grip-to-grip separation	150 mm
Extensometer	static contact-extensometer with 50 mm gauge length + 50 % (25 mm)
Test speed	1 mm/min

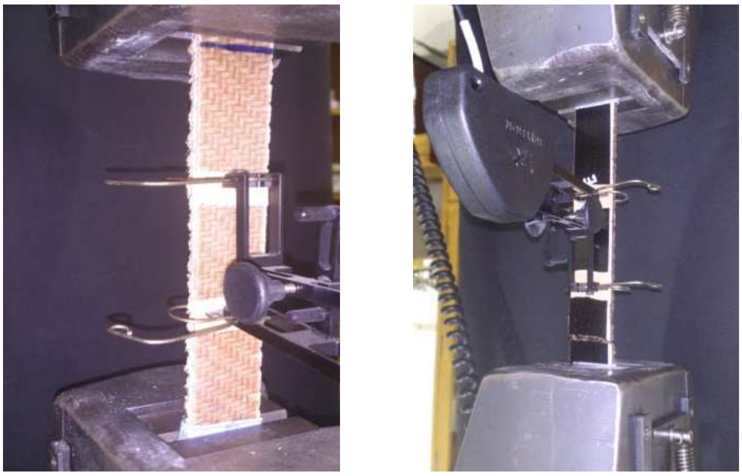

Figure 29 - Specimens under tensile testing

Table 19 - Flexion test conditions

Testing standard	EN ISO 14125:1998 Fibre-reinforced plastic composites. Determination of flexural properties
Equipment:	universal testing machine INSTRON Model 4302
Load cell	10 kN with an accuracy grading of 0,5
Nominal length	250 mm
Spam	89 mm (sample 1); 44.4 mm (sample 3); 100.9 mm (sample 4)
Test speed	1 mm/min

Figure 30 - Specimens under bending test

Table 20 - Interlaminar shear test conditions

Testing standard	EN ISO 14130:1997 Fibre-reinforced plastic composites. Determination of apparent interlaminar shear strength by short-beam method
Equipment:	universal testing machine INSTRON Model 4302
Load cell	10 kN with an accuracy grading of 0,5
Nominal length	55 mm – 65 mm
Spam	89 mm (sample 1); 44.4 mm (sample 3); 100.9 mm (sample 4)
Test speed	1 mm/min

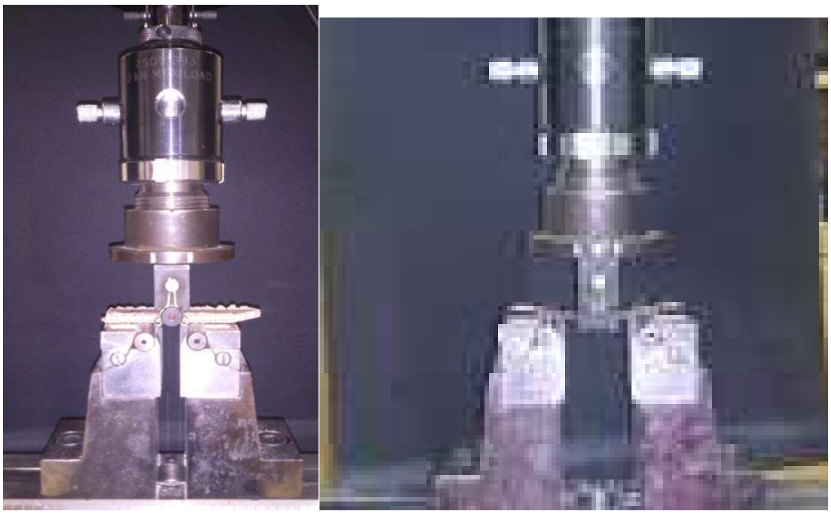

Figure 31 - Specimens under interlaminar shear strength test

Table 21 - Charpy test conditions

Testing standard	EN ISO 179-1: Plastics. Determination of Charpy impact properties. Part 1: Non-instrumented impact test
Equipment:	DMG
Nominal pendulum energy, J	300
Span	40 mm
Method used	ISO 179-1/ 2 n
Specimen type	1 (adapted, but with higher thickness)
Number of test specimens	3

a) *b)*

Figure 32 – Impact machine: a) front view; b) lateral view

6.3.2.3 Test results

The results obtained are presented in Table 22~~Table 22~~, Table 23~~Table 23~~, Table 24~~Table 24~~ and Table 24~~Table 24~~. The tests are not yet concluded and as soon as possible more properties will be determined. However, there are no results for composite constituted by polyester resin and natural fibre mat on surfaces and unidirectional glass fibres in the core (sample type E), because the samples do not have the required dimensions for testing, with the exception of the preliminary Charpy impact test of sample type E.

Table 22 - Test results of sample lamella sandwich constituted by Synolite ZW 7961 – UP and 0/90º Jute fabric on surfaces and cork in the core (sample 9 of Table 16~~Table 16~~)

Tensile (fibres at 90º)	Elastic modulus (MPa)	3148 ± 196
	Stress at break (MPa)	28,3 ± 1,0
	Strain at break (%)	1.4 ± 0.1
Bending (fibres at 45º)	Flexural modulus (MPa)	2444 ± 99
	Flexural strength (MPa)	44,4 ± 2.3
	Flexural strain (%)	2.5 ± 0,2
Bending (fibres at 90º)	Flexural modulus (MPa)	3335 ± 145
	Flexural strength (MPa)	56.6 ± 3.2
	Flexural strain (%)	2.2 ± 0.2
Interlaminar Shear Strength (fibres at 45º)	Interlaminar Shear Strength (MPa)	3.2 ± 0.2
Interlaminar Shear Strength (fibres at 90º)	Interlaminar Shear Strength (MPa)	3.4 ± 0.2
HDT	Heat Deflection Temperature (ºC)	79 ± 1

Table 23 - Test results of compression-moulded flax+furan (sample 2 of Table 16~~Table 16~~)

Tensile (fibres at 45º)	Elastic modulus (MPa)	5089 ± 113
	Stress at break (MPa)	34.6 ± 4.0
	Strain at break (%)	2,5 ± 0.1
Tensile (fibres at 90º)	Elastic modulus (MPa)	5926 ± 410
	Stress at break (MPa)	45.2 ± 2.0
	Strain at break (%)	1.3 ± 0.2
Bending (fibres at 45º)	Flexural modulus (MPa)	3577 ± 204
	Flexural strength (MPa)	67.5 ± 5.5
	Flexural strain (%)	3.4 ± 0.3
Bending (fibres at 90º)	Flexural modulus (MPa)	4840 ± 540
	Flexural strength (MPa)	84.3 ± 37
	Flexural strain (%)	2.4 ± 0.2
Interlaminar Shear Strength (fibres at 45º)	Interlaminar shear strength (MPa)	3.3 ± 0.2
Interlaminar Shear Strength (fibres at 90º)	Interlaminar shear strength (MPa)	4.1 ± 0.2
HDT	Heat Deflection Temperature (ºC)	105 ± 1

Table 24 - Test results of flax/furan prepreg on surfaces and cork in the core (sample 7 of Table 16~~Table 16~~)

Tensile (fibres at 90º)	Elastic modulus (MPa)	4656 ± 294
	Stress at break (MPa)	28.8 ± 2.0
	Strain at break (%)	1.2 ± 0.1
Bending (fibres at 90º)	Flexural modulus (MPa)	1735 ± 102
	Flexural strength (MPa)	38.4 ± 1.5
	Flexural strain (%)	5.0 ± 0.4
Interlaminar Shear Strength (fibres at 90º)	Interlaminar shear strength(%)	2.6 ± 0.3
HDT	Heat deflection Temperature (ºC)	68 ± 1

Table 25 - Test results of sample polyester resin - natural fibre mat on surfaces and unidirectional glass fibres in the core (sample 6 of Table 16)

Resistance to impact Charpy (ISO 179-1/ 1* n	Impact Resistance (kJ/m^2)	496 ± 47 (P)
	Type of failure	Shear

6.3.2.4 Discussion and analysis of results

6.3.2.4.1 Lamella sandwich of UP - 0/90º jute fabric on surfaces and cork in the core

The tensile stress of this UP/jute-cork composite is around the lower reported typical values of some thermoplastic synthetic polymers (HDPE, PP, PS) [1, 2] and similar to some biobased polymers (cellulose acetate butyrate and high density polyethylene) [3], but below of typical tensile stress of thermosetting synthetic polymers (epoxy and polyester resin) [1, 2],

The tensile stress at break is below the typical values reported in the literature for the majority of composites (including bio based), with exception of coconut spathe-fibre reinforced epoxy composites, which reported tensile stress is in the range (9 ± 2, 44 ± 15) [4].

The tensile strain at break is typical of thermosetting materials, synthetic or bio based [3], as well as like some reinforced composites [4, 5] and around typical values for jute fibers (1.5%-1.8%).

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The composite tested with fibres oriented at 90º shows greater flexural strength than when fibres are oriented at 45º.

The bending stress of this composite is above typical values of biopropylene (plant starches bio-based) and similar to the reported typical values of epoxy resins [1, 2] and some bio-based polymers (cellulose acetate and cellulose acetate butyrate) as well as some wood composites [3], but slightly below of typical flexural stress of glass reinforced bio-based thermoplastic polyurethane (GRTPU) [3] and ramie-fibre reinforced composites [6].

The composite with fibres oriented at 45º showed greater interlaminar shear strength than when fibres are oriented at 90º, contrarily what was seen from tensile and flexural results.

All specimens of this sample showed interlaminar shear failure by mixed modes of failure (shear and tension). Thus, calculated values are not all apparent interlaminar shear strengths and according to the ISO 14130 the failures should be identified as “unacceptable” interlaminar shear fracture.

Although the interlaminar shear stress is very dependent of the method used [7] it may be said in a simplified analysis that the interlaminar shear strength of this composite is below the apparent interlaminar shear strength of an unidirectional graphite/epoxy, as well as the typical values obtained with some engineering composites [8-9].

6.3.2.4.2 Composite constituted by polyester resin and natural fibre mat on surfaces and unidirectional glass fibres in the core

Up to this moment, LNEC has not received a sufficient amount of samples to perform all the desired testing, because the delivered samples were sent in the form of square pieces of small dimensions. As the sample has a high thickness and reduced length, it was not possible to perform any of the aforementioned tests. The only test carried out were Charpy tests, but using a span below the recommended value. Thus, these results are not fully reliable and more samples are needed in order to have a complete picture of the mechanical properties of this composite.

It is not possible to follow entirely the test standard, because the high thickness of the sample requires a higher span than is possible in current experimental conditions. Moreover, the sample is very stiff and only allows to get reliable results using a pendulum with nominal energy of 300 J.

6.3.2.4.3 Compression-moulded flax-furan prepreg

The tensile stress of this flax/furan is inside the typical range of values obtained with some thermoplastic (LDPE, PA, PS) [1, 2] and thermosetting synthetic polymers (epoxy and polyester resin) [1, 2] and it is above the majority of typical values obtained with bio-polymers, namely ethylene acrylate starch hybrid resin, high density polyethylene sugarcane based, biopropylene plant starches and compostable corn starch based [3]. It is similar to ones typical of some biocomposites based on lignin, starch, cellulose, organic additives, natural resins or waxes and natural reinforcing fibers, PA 11 100 % castor oil based, as well as for some biopolymers based on cellulose acetate butyrate [3], but is lower than biocomposites based on epoxy or polyester ramie-fibre reinforced [4].

The tensile strain at break is typical of thermosetting materials, synthetic or bio based [3], as well as like some reinforced composites [5, 6].

The composite with fibres oriented at 90º shows greater flexural strength than that with fibres oriented at 45º. The flexural modulus and the flexural strength of the flax-furan analysed showed values above typical values reported for common thermoplastics [10] as well as the majority of biocomposites [3]. The flexural strength is similar to the reported values of ramie-fibre reinforced composites [6], but below of typical bending stress of glass fibre reinforced epoxy composites [5].

All specimens of this sample showed interlaminar shear failure by tension. Thus, calculated values are not all apparent interlaminar shear strengths according to what it is stated in ISO 14130. In a similar manner to that was previously referred in 6.3.2.4.1, the interlaminar shear strength of this composite is below the interlaminar shear strength of the unidirectional graphite/epoxy, as well as the typical values obtained with some engineering composites [8-9].

However, comparing the results obtained with different 4 samples sent to LNEC, it can be affirmed that the flax-furan prepreg sample showed the highest mechanical strength.

6.3.2.4.4 Composite constituted by flax/furan prepreg on surfaces and cork in the core

The elastic modulus of this furan/flax-cork composite is below the reported values for fibers, including flax (27.6 GPa) [12-17] and below ramie-fibre reinforced composites [4], but is similar to typical elastic modulus of some polymers [11] and above the majority of commercial bio-polymers [3].

The tensile stress of this furan/flax-cork composite tested and here reported is around the lower reported typical values of some thermoplastic synthetic polymers [1, 2] and similar to some biobased polymers (high density polyethylene sugarcane based, some commercial Arboblends and some commercial glass reinforced thermoplastic polyurethane) [3], but below of typical tensile stress of ramie-fiber reinforced epoxy composites [4] and synthetic engineering composites

The tensile stress at break is below the typical values reported in the literature for the majority of synthetic composites [8-10], but similar to bio-based composites as for example coconut spathe-fibre reinforced epoxy composites, whose reported tensile stress is in the range (9 ± 2, 44 ± 15) [5].

The tensile strain at break is below typical values for flax fibers (2,7%-3,2%) [6] and typical of thermosetting materials, as well as like some reinforced composites [7]. The flexural modulus of the flax/furan-cork composite show values that are inside the range of typical values reported for the majority of biocomposites [3].

The bending stress of this composite is above typical values of biopropylene (plant starches, bio-based) and similar the reported typical values of some bio-based polymers (Cellulose acetate and cellulose acetate butyrate) [3], but below of typical flexural stress of wood composites, glass reinforced bio-based thermoplastic polyurethane (GRTPU) [3] and ramie-fibre reinforced composites [6].

All specimens of this sample showed interlaminar shear failure by mixed modes of failure (shear and tension) and like the previous samples, the calculated values are not apparent interlaminar shear strengths. The calculated interlaminar shear strength of this composite is lower than those obtained with previous the composites analysed.

Comparing the results obtained with different composite samples sent to LNEC and tested, it can be affirmed that the flax/furan-cork sample showed the worst delamination behaviour, but better mechanical strength that lamella sandwich constituted by Synolite ZW 7961 – UP and 0/90º Jute fabric on surfaces and cork in the core.

6.3.2.5 Summarised results

Aiming to evaluate the mechanical properties of each composite, the tensile and flexural proprieties of the composites were assessed according to the previously defined test plan, however some modifications were made to the plan due to the insufficient amount of material made available to LNEC in respect to what was requested. All tests were performed at ambient temperature, except in case of the heat deflection temperature (HDT) test.

From the results obtained it is possible to conclude the following:

- The compression-moulded flax+furan sample shows the best performance and higher mechanical strength, when compared with other samples tested (lamella sandwich of UP and 0/90º jute fabric on surfaces and cork in the core, and flax/furan on surfaces and thick cork prepreg in the core).
- The composite constituted by flax/furan on surfaces and thick cork prepreg in the core which is designed from sample 3 adding cork in the core, showing delamination during test specimen preparation. Thus, techniques to modify the surface/interface/interphase should be improved, in order to assure a performance similar or better than composite without inner cork layer.

Additional work is still being done for a better performance evaluation of the aforementioned composites. More samples are also needed in order to have a complete picture of the mechanical properties of all composites.

6.3.3 *Reaction to fire tests (components and elements)*

The aim of these tests was to obtain solutions that would enable the best possible RtF classification. The target is to obtain RtF class **B** (best classification attained by organic products) required by fire safety regulations in some end-uses (and countries).

In order to assess the *specific* fire performance of the components (materials) which would be selected to produce the different kit components it was foreseen (Table 15~~Table 15~~) to perform ignitability tests over the following systems/material combinations (for all applications) previously identified. Samples representative of all these combinations have been produced by different partners and sent to LNEC.

Ignitability tests were performed to assess and screen the combinations with regards to:

- The degree of ignitability under attack (edge and surface) of a small ignition source (small flame);
- The speed and extension of flame propagation.

Ignitability tests were performed according EN ISO 11 925-2, using standard size test specimens (250 mm x 90 mm), unless material availability was limited.

These tests - required for any RtF classification from B to E - were used here with the aim to assess the *basic* fire performance of the different considered options. The results of the tests allowed the identification, on the one hand the low performing products and on the other hand the weak points and improvement needs for the most promising ones.

The following tables present all product samples submitted to ignitability tests. The figures illustrate the main performance aspects of some of the product samples submitted to ignitability tests.

Table 26 – Assessment of basic performance of materials (ignitability)

Sent by	Material	Ignitability performance	Remarks
Netcomposites	Furan-flax prepreg	Under edge attack ignition may occur and be sustained	Natural fibre reinforcement seems be responsible for ignition/combustion
Netcomposites	Compression-moulded flax+Furan sandwich (with cork)	Under edge attack ignition may occur and be sustained	Natural fibre reinforcement and eventually aggl. cork are responsible for ignition/combustion
Netcomposites	Vacuum-bagged flax+Furan sandwich (with cork)	Under edge attack ignition may occur and be sustained	Natural fibre reinforcement and eventually aggl. cork are responsible for ignition/combustion
KUV	MAT preform selected (Fibrimat F300 from Ecotechnilin)	Easily ignited Fast flame propagation Burned completely	
Netcomposites	Vacuum-bagged sandwich (with cork NL10)	No sustained flaming under surface attack Different grades of sustained flaming and combustion extension	Natural fibre reinforcement is, probably, the main cause of combustion spread
Netcomposites	Compression-moulded sandwich (with cork NL10)		

a) **b)** **c)**

a. Edge attack – no sustained flaming
b. Edge attack - self extinguished flaming
c. Edge attack - sustained flaming)

Figure 33 - Furan-flax prepreg

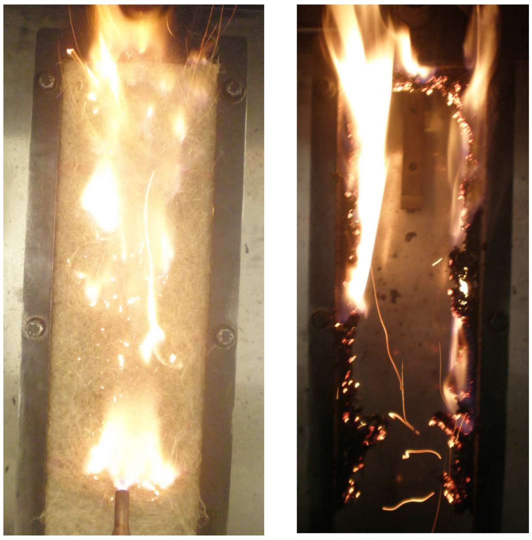


Figure 34 - MAT preform selected (Fibrimat F300 from Ecotechnilin)

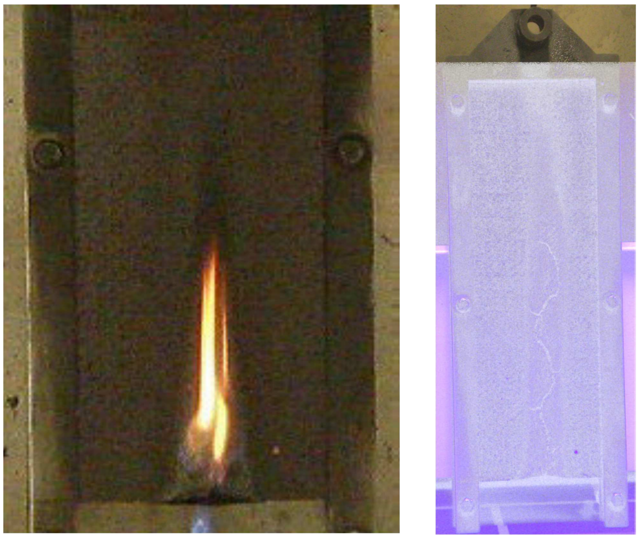


Figure 35 - Vacuum-bagged sandwich (with cork NL10)

Table 27 – Test samples 7 from Table 16~~Table 16~~ (development of SCK lamellae)

Sent by	**Material**	**Ignitability performance**	**Remarks**
ACCIONA	Lamella Sandwich: Synolite ZW 7961 – UP from DSM-0/90 Jute 2x2 twill fabric 400 g/m²+ cork core+ Synolite ZW 7961 – UP from DSM-0/90 Jute 2x2 twill fabric 400 g/m²	Ignited Flame propagation Burned completely	Use as false ceiling element would require fire performance improvement

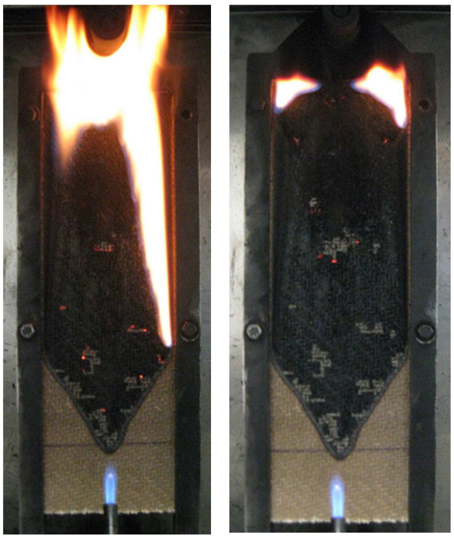
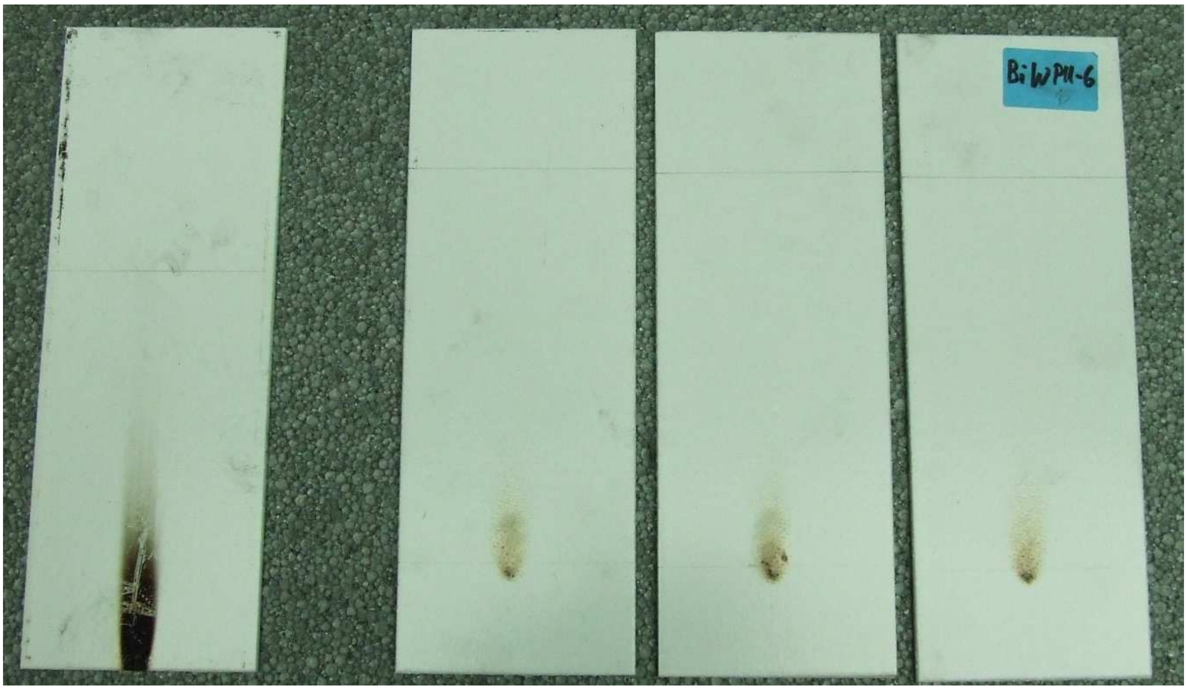


Figure 36 - Lamella Sandwich: Synolite ZW 7961 – UP from DSM-0/90, Jute 2x2 twill fabric 400 g/m²+ cork core+ Synolite ZW 7961– UP from DSM-0/90 Jute 2x2 twill fabric 400 g/m²

Table 28 – Tests for the development of the coating

Sent by	**Material**	**Ignitability performance**
SHR	Ref. PhWPU-1 - Core phenolic HPL + coating 2K water PU	No sustained ignition
SHR	Ref. BiWPU-1 - Core Biopol-flax + coating 2K water PU	Complete combustion under edge flame attack No sustained ignition under surface flame attack
SHR	Ref. PhSPU-1 - Core phenolic HPL + coating 2K solvent PU	No sustained ignition
SHR	Ref. BiSPU-1 - Core Biopol-flax + coating 2K solvent PU	Complete combustion under edge flame attack No sustained ignition under surface flame attack
SHR	Ref. PhAl-1 - Core phenolic HPL + coating 1K Alkyd	No sustained ignition
SHR	Ref. BiAl-1 - Core Biopol-flax + coating 1K Alkyd	Complete combustion under edge flame attack No sustained ignition under surface flame attack
SHR	PhFo-Core phenolic HPL + Coating foil white	No sustained ignition
SHR	PhFo-Core phenolic HPL + Coating foil transparent	No sustained ignition
SHR	BiFo-Core Biopol-flax + Coating foil white	Complete combustion under edge flame attack
SHR	BiFo-Core Biopol-flax + Coating foil transparent	Complete combustion under edge flame attack No sustained ignition under surface flame attack



a) edge attack surface attack

Figure 37 - Ref. BiWPU-1 - Core Biopol-flax + coating 2K water PU

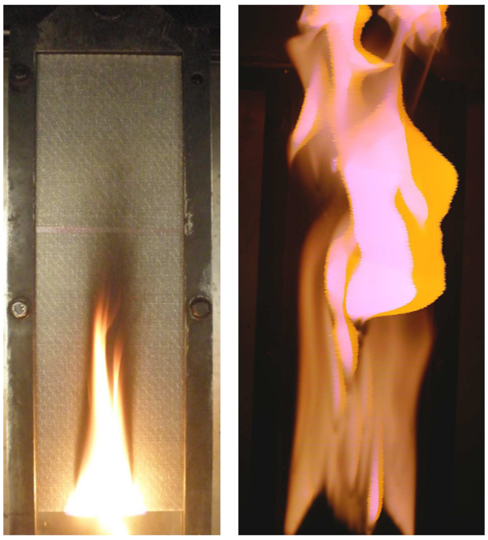


Figure 38 - Biopol, transparent foil finish (edge flame attack)

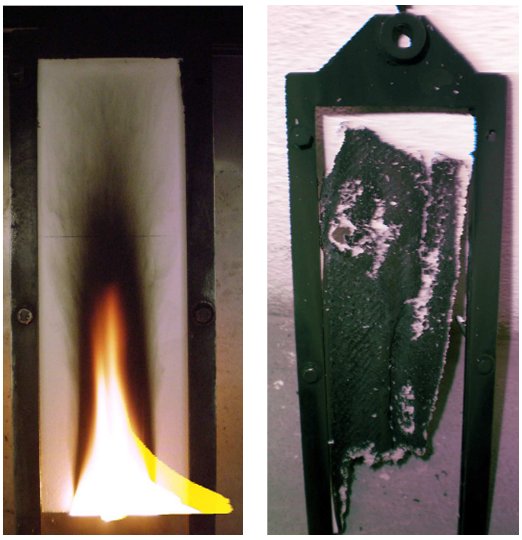


Figure 39 - Biopol white foil finish (edge flame attack)

Table 29 – Test samples 6 from Table 16~~Table 16~~ (development of pultruded profiles)

Sent by	Material	Ignitability performance	Remarks
Excel Composites	Resin – Polyester UL94V0 – Silver grey (C022) Natural Fibre mat on surfaces (CE supply) + 37gsm Surface veil Unidirectional Glass fibres in the core – 4800 tex	No sustained ignition Charred surface in at the flame impingement point	

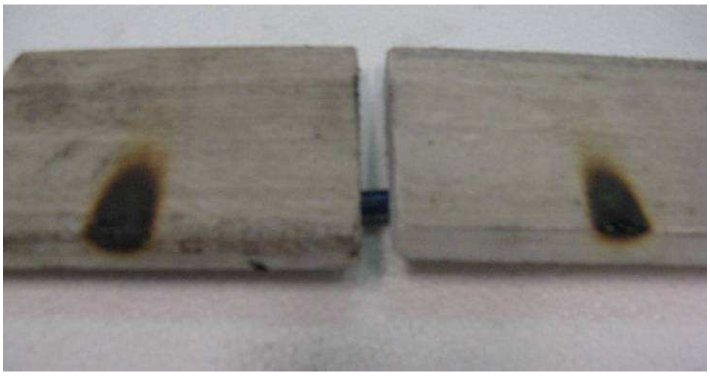


Figure 40 - Resin – Polyester UL94V0 – Silver grey (C022); Natural Fibre mat on surfaces (CE supply) + 37gsm Surface veil ; Unidirectional Glass fibres in the core – 4800 tex

Table 30 – Test samples 3 of Table 16~~Table 16~~

Sent by	**Material**	**Ignitability performance**	**Remarks**
Amorim ACC	Agglomerated composition cork (ref8821), density = 293 kg/m^3, 2 mm thick	Easily ignited Fast flame propagation Burned completely	Must be protected from flame Fire retardant additive desirable
Amorim ACC	Agglomerated composition cork (ref8821), density = 206 kg/m^3, 5 mm thick	Easily ignited Flame propagation is limited (< 1 50 mm) Self-extinguishes before total combustion	Must be protected from flame (Fire retardant additive desirable)
Amorim ACC	Agglomerated composition cork (ref8821), density = 202 kg/m^3, 6 mm thick	Easily ignited Flame propagation is limited (< 1 50 mm) Self-extinguishes before total combustion	Must be protected from flame (Fire retardant additive desirable)
Amorim ACC	Agglomerated composition cork (ref8821), density = 223 kg/m^3, 10 mm thick	Easily ignited Flame propagation is limited (< 1 50 mm) Self-extinguishes before total combustion	Must be protected from flame (Fire retardant additive desirable)

Table 31 – Test samples 7 from Table 16~~Table 16~~

Sent by	**Material**	**Ignitability performance**	**Remarks**
IVW	2 layers flax/furan prepregs – 6 mm NL20 cork – 2 layers flax/furan prepregs Processed in the semi continuous compression molding machine. The maximum temperature was 155 °C and the pressure was 10 bar	Ignition under edge flame attack Sustained flaming eventually on both sides of the test specimen	Ignition and flame spread seems to be supported first by the natural fibre reinforcement and later by agglomerated cork

6.3.4 Summarised results

So far, the initial ignitability tests on the basic performance of the materials showed that:

- Furan resin does not ignite easily.
- Furan/flax prepregs may ignite and sustain a slow propagation of combustion.
- Flax (non-woven) mat is easily ignited and flame spreads very fast and total combustion is the final result.
- Degradation of the furan surface (cracking, delamination, blistering) exposes the natural fibre reinforcement that will sustain combustion.
- On the contrary, Biopol resins ignite (flame edge attack) and sustain the development and propagation of flame resulting in total combustion of the material.

- As expected, if exposed to flame attack agglomerated cork layers ignite (easily if thickness is small) and sustain combustion.
- Edges must be protected (in the end product/kit). Practical/cost effective solutions must be studied.
- So far only a RtF class E is “guaranteed” for most of the different component/material solutions.

6.3.5 Ongoing work / Difficulties / Additional work still being done

Screening/indicative SBI tests have started over one of the components of IPK, composed by a sandwich panel [Jute-furan prepregs and one layer of NL20 with 12 mm and Jute-furan prepregs].

First test on an uncoated panel revealed that:

a) the surface starts to burn (maybe due to the jute reinforcement being exposed after cracking of furan layer;
b) localised cracking and delamination (curling) of the furan/jute layer exposes the agglomerated cork surface;
c) a cork surface sustains combustion and although not all thickness of the panels involved a considerable amount of heat is released;
d) due to char layer formed by the combustion of cork the penetration of combustion through the thickness of the panel is relatively slow.

The result is that no better than class **E** is achieved

Shall be avoided that natural fibre reinforcement and agglomerated cork (or other organic core) become exposed to flames/heat source (edges may be protected with a fire resistant sealant but, so far, not the furan resin surface).

A new SBI test specimen is being prepared and will be tested in the beginning of December. 2K water based PUR intumescent paint coat/finish [Sayerlack’s “*TE Clear waterborne fire-retardant system*”] will be applied over the surfaces (2 coats – 400 g/m^2)) of the sandwich panel [Jute-furan prepregs + 1 layer of NL20 with 12mm + Jute-furan prepregs].

7 Conclusions

The BioBuild project entails the design and construction of four case studies. These refer to both external and internal systems and specifically: an External Wall Panel (EWP), an External Cladding Kit (ECK), an Internal Partition Kit (IPK) and a Suspended Ceiling Kit (SCK).

All systems have been assessed on specific criteria, including fire-safety; dimensional stability; in-service resistance to loads; thermal and acoustic insulation; energy efficiency; and sustainability.

Since the design of the EWP is still ongoing at present stage future changes and modifications regarding both the production process and the materials can happen.

Several conclusions were obtained from the ongoing work. Although they are summarised in the “Executive summary” of this document it is important to stress here that the main conclusion drawn from the processing of furan resin and glass fibres is that this furan resin was unsuitable for use with natural fibres due to the acidic catalyst used to cure it. From the processing point of view, bio-polyester resins in combination with flax fibres seems to be the best option in order to manufacture pultruded profiles with natural fibres and bio-resins.

The initial ignitability tests on the basic performance of the materials showed, especially, that:

- Furan resin does not ignite easily.
- Furan/flax prepregs may ignite and sustain a slow propagation of combustion.
- Biopol resins ignite (flame edge attack) and sustain the development and propagation of flame resulting in total combustion of the material.
- Edges must be protected (in the end product/kit). Practical/cost effective solutions must be studied.
- So far only a RtF class E is “guaranteed” for most of the different component/material solutions.

8 Bibliography

[1] Malkapuram, R, Kumar, V and Yuvraj, S N, Recent Development in Natural Fibre Reinforced Polypropylene Composites, Journal of Reinforced Plastics and Composites, 2008, Vol. 28, pp. 1169-1189.

[2] Holbery, J and Houston D, Natural-Fiber-Reinforced Polymer Composites in Automotive Applications, 2006, JOM, Vol. 58, No. 11, pp. 80-86.

[3] http://www.specialchem4bio.com/ trough the link "Bio-based Chemicals & Materials Solutions", November 2013

[4] S.M. Sapuan, M.N.M. Zan, E.S. Zainudin and Prithvi Raj Arora, Tensile and flexural strengths of coconut spathe-fibre reinforced epoxy composites, Journal of Tropical Agriculture 43 (1-2): 63-65, 2005

[5] Satnam Singh, Pardeep Kumar, S.K. Jain, An experimental and numerical investigation of mechanical properties of glass fiber reinforced epoxy composites, Adv. Mat. Lett. 2013, 4(7), 567-572

[6] Tresna Priyana Soemardi, Tensile and Flexural Strength of Ramie Fiber Reinforced Epoxy Composites for Socket Prosthesis Application, Academia.EDU

[7] M. Li , R. Matsuyama , M. Sakai "Interlaminar shear strength of C/C-composites: the dependence on test methods, Carbon 37 (1999) 1749–1757

[8] P. Feraboli, K.T. Kedward, "Four-point bend interlaminar shear testing of uni- and multi-directional carbon/epoxy composite systems", Composites: Part A 34 (2003) 1265–1271

[9] O¨. Unal , V. Dayal "Interlaminar shear strength measurement of ceramic composites by asymmetric four point bend shear test", Materials Science and Engineering A340 (2003) 170/174

[10] EN ISO 178:2010 Plastics - Determination of flexural properties

[11] Mark, James E. (Editor), Polymer Data handbook, pp. 1018, Oxford University Press, New York, ISBN 0-19-510789-6, 1999

[12] Wambua, P, Ivens, J and Verpoest, I, *Natural Fibres: Can They Replace Glass in Fibre Reinforced Plastics*, Composites Science and Technology, 2003, Vol. 63, pp.1259-1264.

[13] Ahmad, I, Baharum, A and Abdullah, I., *Effect of Extrusion Rate and Fiber Loading on Mechanical Properties of Twaron Fiber-thermoplastic Natural Rubber (TPNR) composites*, Journal of Reinforced Plastics and Composites, 2006, Vol. 25, pp. 957-965.

[14] Nabi Saheb, D. and Jog, J P, Natural Fiber Polymer Composites: A Review, Advanced in Polymer Technology, 1999, Vol. 18, pp. 351-363.

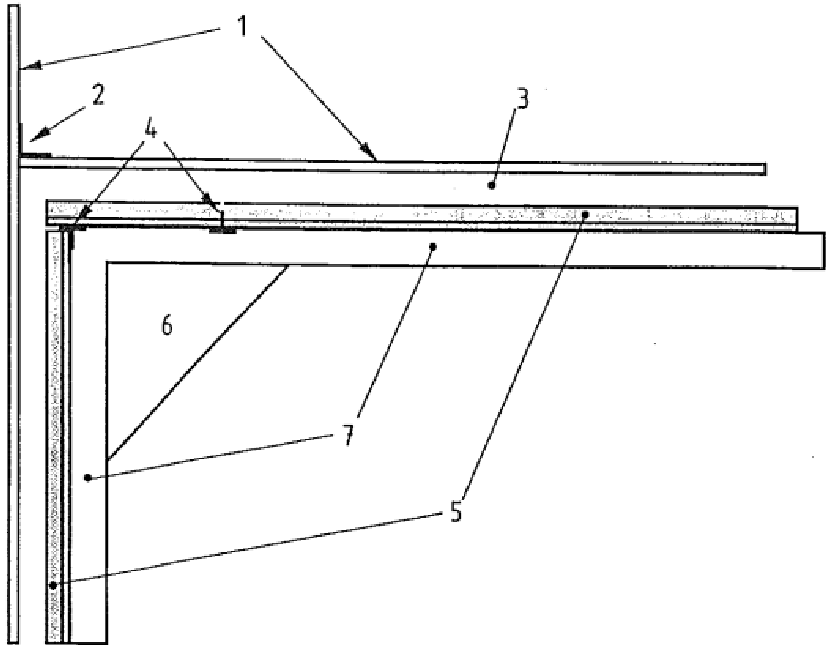
[15] Hajnalka, H, Racz, I and Anandjiwala, R D, Development of HEMP Fibre Reinforced Polypropylene Composites, Journal of Thermoplastic Composite Materials, 2008, Vol. 21, pp.165-174.

[16] Smithers RAPRA, http://www.rapra.net/composites/material-selection/reinforcement-types.asp, October 2013

[17] Hajnalka, H, Racz, I and Anandjiwala, R D, Development of HEMP Fibre Reinforced Polypropylene Composites, Journal of Thermoplastic Composite Materials, 2008, Vol. 21, pp.165-174.

ANNEX A - BioBuild Full-Size System Testing - External Wall Panels (EWP)

Test	Test method *(EN, ISO, …)*	**Test samples *(dimensions – mm/ quantity)***		Quantity	Remarks	Partner
		According to test method	**Maximum permitted by the apparatus**			
Single Burning Item (SBI)	EN 13823	1500 x 1000 + 1500 x 495 x (200 max)	1500 x 1000 + 1500 x 495 x (max 200) Flat test samples	3 + 3 (minimum)	See figure below showing the top view of the test specimen.	LNEC



Key
1 Backing boards
2 L-Profile
3 Air gap
4 Joints
5 Specimen wings
6 Burner
7 U-profiles

Fig. 1 - Example arrangement of specimen and backing boards (schematic drawing)

Test	**Test method** *(EN, ISO, …)*	**Test samples** ***(dimensions – mm/ quantity)***		**Quantity**	**Remarks**	**Partner**
		According to test method	**Maximum permitted by the apparatus**			
Mechanical resistance	ETAG 016 – Part 1		According to figs. 2 and 3	At least 2 (as fig. 2 and fig. 3)	C1 Test to determine the mechanical strength of a simply supported panel subject to positive load: ETAG 016: Part 1, Annex C1. C2 Test to determine the mechanical strength of a fixed panel subject to negative load: ETAG 016: Part 1, Annex C2. See fig. 2 bellow C3 Test to determine the temperature effect on the panel: ETAG 016: Part 3, Annex C4, See fig. 3 below	LNEC
Impact resistance	EOTA TR 01		According to fig. 2	New assemblies should be tested for each impact energy (13 levels) for “Serviceability impact resistance” and for “Safety in use impact resistance” (see note 1 below)	The panels shall be mounted in accordance with the manufacturer's installation specifications, with regard to the intended use (wall or ceiling panel), so that the test assembly corresponds as much as possible with end use conditions. In principle, the most onerous assembly shall be: • panel: the panel with the highest ratio length (or height) over width in its minimum thickness; • span: maximum distance between supports.	LNEC
Dimensional variation (related to water penetration)	ETAG 016: Part 3, Annex C2		According to fig. 3	1	Same test specimen as for Resistance of external wall system to driving rain under pulsating air pressure test	LNEC
Thermal effect and	ETAG 016 – Part 3		According to fig. 3	3	thermal stresses and degradation	LNEC

thermal shock	Annexes C4 and C5					

Note 1 – The required procedure needs a huge number of test specimens. Usually it is accepted that the same test specimen may be submitted to increasing test drop heights until failure of Serviceability impact resistance criteria. As accumulated damage due to previous impact energy levels may impair the test results, the test shall be repeated for the impact energy level where test specimen fails with a new test specimen. For the evaluation of Safety in use impact resistance a similar procedure may be used. Accepting these procedures, just **four test** specimens will be needed.

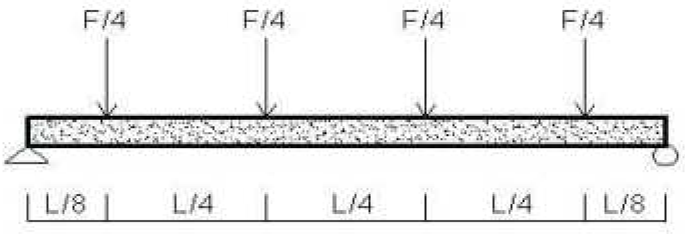


Fig. 2A – Load scheme for C1 and C2 mechanical resistance tests

Note 2 – The load scheme of fig. 2A requires transversal load pads according to the drawing in fig. 2B

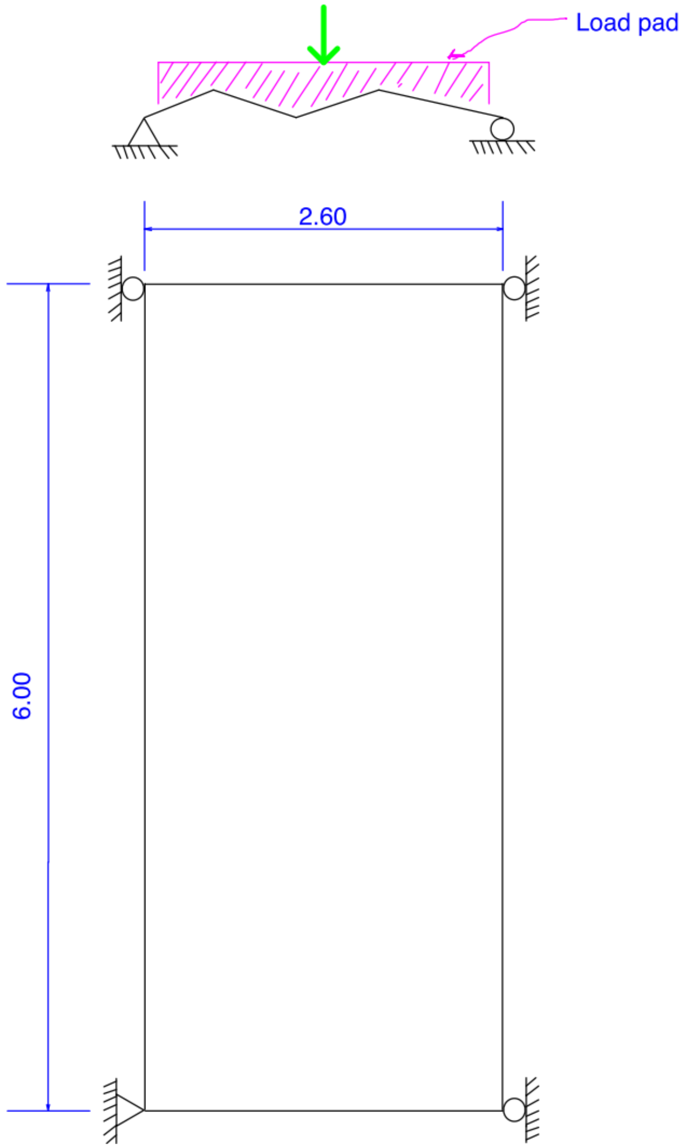


Fig. 2B – Test specimen for C1 and C2 mechanical resistance tests

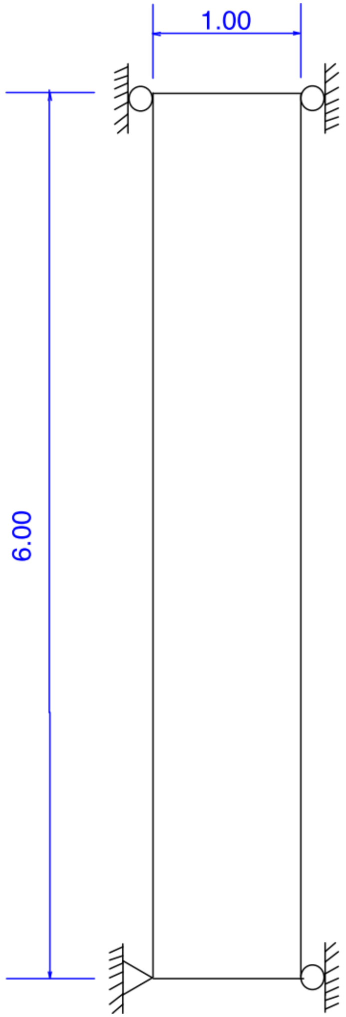


Fig. 3 – Test specimen for C3 mechanical resistance test

Test	Test method *(EN, ISO, …)*	Test samples *(dimensions – mm/ quantity)*		Quantity	Remarks	Partner
		According to test method	Maximum permitted by the apparatus			
Direct airborne sound insulation	EN ISO 140-3; EN ISO 717-1	Depending on the dimensions of the test specimen	3500 wide x 2800 high	The same test specimen	Upper left part of test specimen in fig. 4	LNEC
Sound absorption	EN ISO 354 ; EN ISO 11654 :		3500 wide x 2800 high		Upper left part of test specimen in fig. 4	LNEC
Thermal transmittance	LNEC specifications	-	1190 x 1190 Flat panel		Lower right part of test specimen in fig. 4	LNEC
Air permeability	EN 12114		According to fig. 4		Full test specimen in fig. 4	LNEC
Resistance of external wall system to driving rain under pulsating air pressure (*)	EN 12865		According to fig. 4		Full test specimen in fig. 4	LNEC
Resistance to fixings	UEAtc technical report for the assessment of installation using sandwich panels with a CFC-free polyurethane foam core		According to fig. 4			LNEC
Resistance to eccentric loads	ETAG 016 – Part 3		According to fig. 4	Two test specimens are needed if the vertical and horizontal loads are applied until failure.	To minimize the number of test specimens, it is suggested to use 2 replacement panels 2.30*2.80 to insert in the test specimen of fig. 4.	LNEC

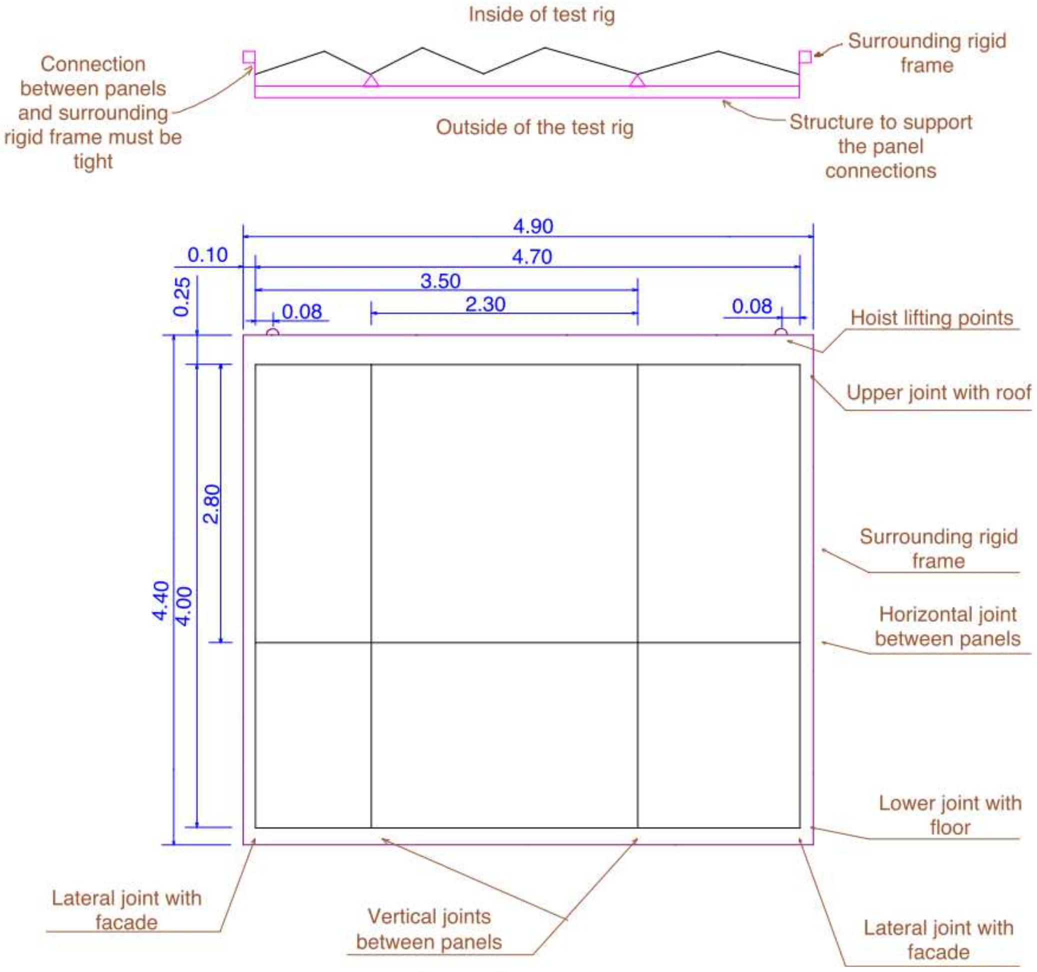


Fig. 4 – Test specimen

Note 3 – Outside the plane of the test rig it is necessary a structure (not completely detailed in fig. 4) connected to the surrounding rigid frame to support the fixings of every panel.

Note 4 - This is a provisional suggestion of test specimens based on the information available at 2013-03-04. The number of test specimens, their shape and dimensions shall be verified when updated information on product is given.

ANNEX B - BioBuild Full-Size System Testing - Internal Partition Kits (IPK)

Test	**Test method** *(EN, ISO, …)*	**Test samples** ***(dimensions – mm/ quantity)***		**Quantity**	**Remarks**	**Partner**
		According to test method	**Maximum permitted by the apparatus**			
Single Burning Item (SBI)	EN 13823	1500 x 1000 + 1500 x 495 x (200 max)	1500 x 1000 + 1500 x 495 x (max 200)	3 + 3 (minimum)	See figure below showing the top view of the test specimen.	LNEC

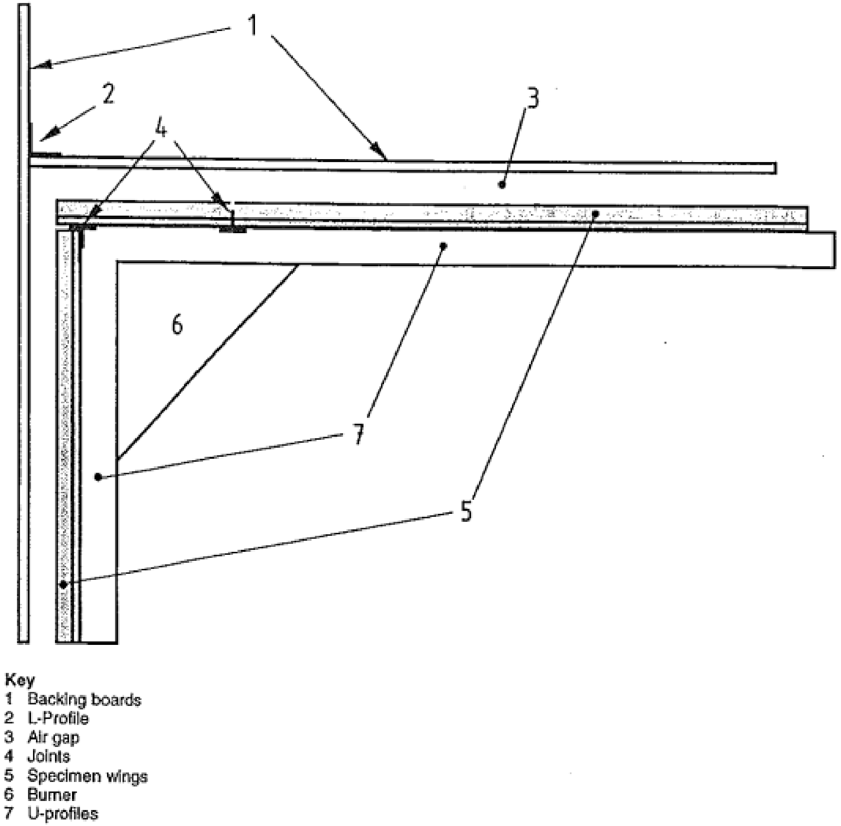
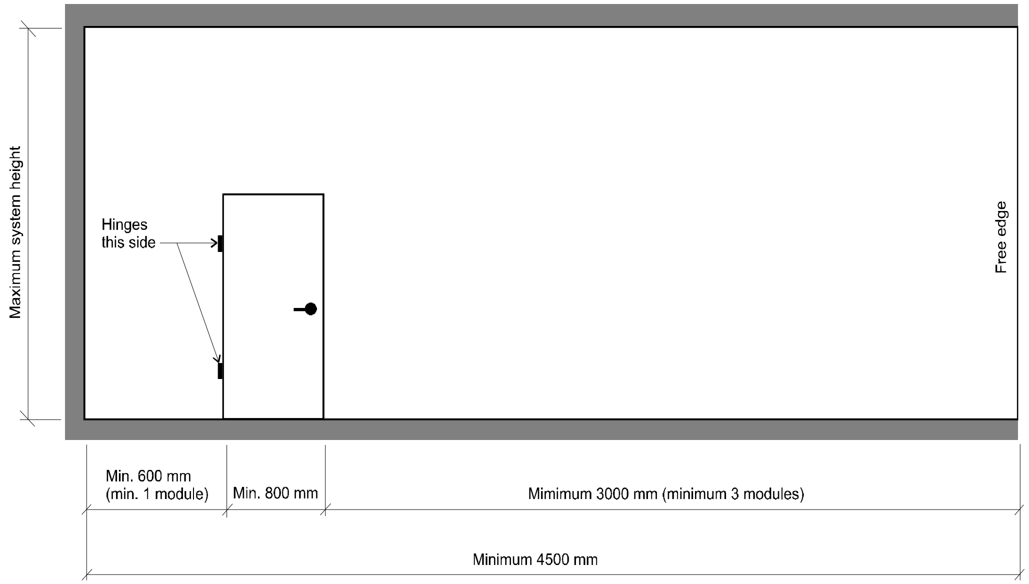


Fig. 1 - Example arrangement of specimen and backing boards (schematic drawing)

Test	**Test method** *(EN, ISO, …)*	**Test samples** ***(dimensions – mm/ quantity)***		**Quantity**	**Remarks**	**Partner**
		According to test method	**Maximum permitted by the apparatus**			
Resistance to structural damage from soft body impact load – 50 kg bag	ISO 7892 and ISO/DIS 7893, with amendments and modifications as described in Annexes C and D of ETAG 003	According to fig. 2		1		LNEC
Resistance to structural damage from hard body impact load – 1 kg steel ball	ISO 7892, and ISO/DIS 7893, with amendments and modifications as described in Annexes C and D of ETAG 003	According to fig. 2		1		LNEC
Resistance to structural damage from eccentric vertical load	ISO/DIS 8413, with amendments and modifications as described in Annexes C and D of ETAG 003	According to fig. 2		1		LNEC
Rigidity of partitions to be used as a substrate for ceramic tiling	Annex E of ETAG 003.	According to fig. 2		1	The test is carried out in place of the test described in clause Resistance to structural damage from soft body impact load – 50 kg bag, and not as a supplement to it.	LNEC



Note 1 - If the test sample does not include a door-set belonging to the partition system, a type of door-set commonly used in the type of partition system being tested shall be fitted in the opening. The door-set shall be installed as shown in Figure 2. The door opens towards the observer.

Figure 2 - Partition sample dimensions

Test	**Test method** *(EN, ISO, …)*	**Test samples** ***(dimensions – mm/ quantity)***		**Quantity**	**Remarks**	**Partner**
		According to test method	**Maximum permitted by the apparatus**			
Direct airborne sound insulation	EN ISO 10140-2; EN ISO 717-1	According to fig. 3		The same test specimen		LNEC
Sound absorption	EN ISO 354 ; EN ISO 11654 :	According to fig. 3			Whenever there are discrete elements (e. g. chairs), special arrangements have to be made	LNEC
Resistance to horizontal linear static load	ISO/DIS 12055, with amendments and modifications as described in Annex D, clause D.5, of ETAG 003	According to fig. 3			Alternatively and where appropriate, the resistance to horizontal linear static load can be determined by calculation according to EN 1991-1-1	LNEC

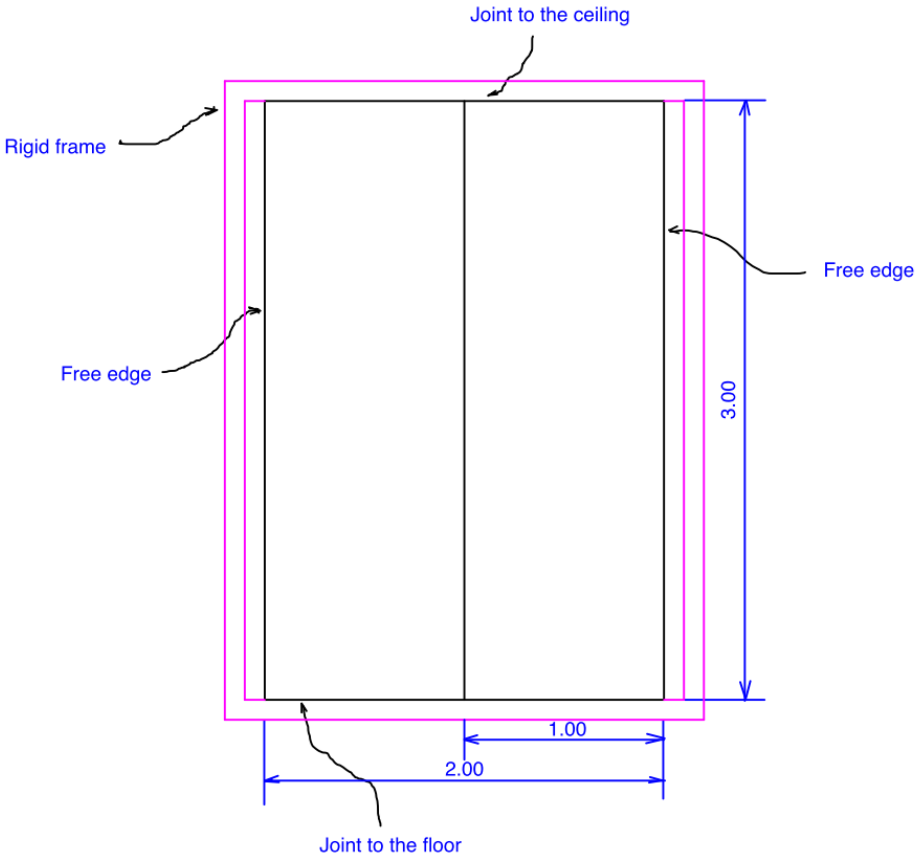


Figure 3 - Partition sample dimensions

Test	**Test method** *(EN, ISO, …)*	**Test samples** ***(dimensions – mm/ quantity)***		**Quantity**	**Remarks**	**Partner**
		According to test method	**Maximum permitted by the apparatus**			
Resistance to deterioration Physical agents	ETAG 003		950 x 950		A test sample that fully represents the partition under consideration shall be submitted to the following hygrothermal conditions: - an atmosphere of 20 °C – 25 °C on either side of the partition at 25 %RH – 30 %RH for 7 days, then the temperature is reduced to 5 °C for 7 days; - an atmosphere of 20 °C – 25 °C at 25 %RH – 30 %RH on one side and 0 °C – 5 °C at 85 %RH – 95 %RH on the other for a period of 28 days; - for the effects of radiation, the partition shall be subjected on one of the faces to a localised radiation allowing the temperature of the exposed parts to be brought to maximum 50 °C ± 5 °C for 6 hours. After each test, the deflection of the partition shall be measured.	LNEC

ANNEX C - BioBuild Full-Size System Testing - Suspended Ceiling Kits (SCK)

Test	**Test method** *(EN, ISO, …)*	**Test samples** ***(dimensions – mm/ quantity)***		**Quantity**	**Remarks**	**Partner**
		According to test method	**Maximum permitted by the apparatus**			
Single Burning Item (SBI)	EN 13823	1500 x 1000 + 1500 x 495 x (200 max)	1500 x 1000 + 1500 x 495 x (max 200)	6 + 6 (minimum)	Reaction to fire testing and classification shall be based on the performance of each component making up the ceiling, which shall be stated separately in the results. See figure below showing the top view of the test specimen. The suspended ceiling profiles will be applied to SBI in two different positions, horizontal position and vertical position, in order to evaluate the reaction to fire for these two possible exposures.	LNEC

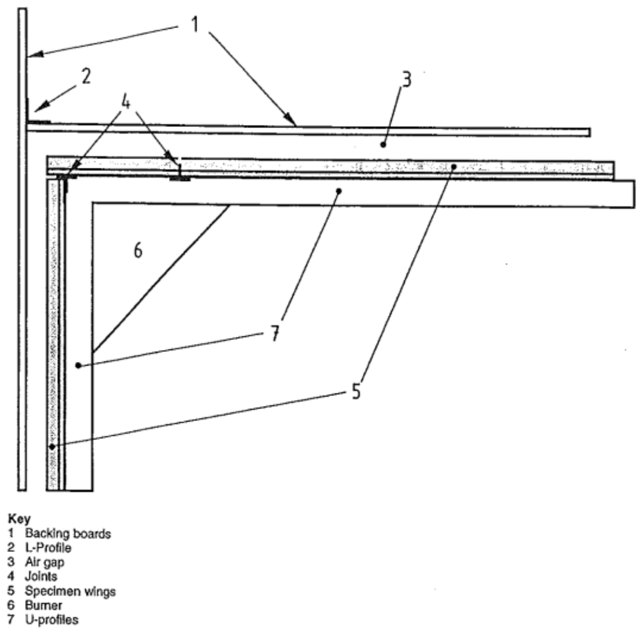


Fig. 1 - Example arrangement of specimen and backing boards (schematic drawing)

Test	**Test method** *(EN, ISO, …)*	**Test samples** ***(dimensions – mm/ quantity)***		**Quantity**	**Remarks**	**Partner**
		According to test method	**Maximum permitted by the apparatus**			
Flexural tensile strength	Annex F of EN 13964			Five tests per type and size of ceiling membrane component shall be carried out when determining the loadbearing capacity.	The test specimen shall consist of a membrane component of full size and with characteristics (e.g. density and thickness) representative of the membrane used in practice.	LNEC
Loadbearing capacity (substructure)	5.2 and 5.3 of EN 13964				This testing method is applicable for metal substructures, suspensions and connecting elements **whose loading capacity cannot be determined by calculation.** The specimen to be tested shall include	LNEC

					all the characteristics of those products as used on site. The load bearing capacity of metal structures shall be determined by the following tests on individual members at various spans and loads. The suspension test shall include both its connections to the top fixing and to the substructure profile.	
Suspension component – Functional test	Annex G of EN 13964					LNEC
Sound absorption	EN ISO 354 EN ISO 11654	3150 x 3150	4000 x 5000			LNEC

ANNEX D – Biobuild Full-Size System Testing - External Cladding Kit

Table 1 – Type of panel fixing

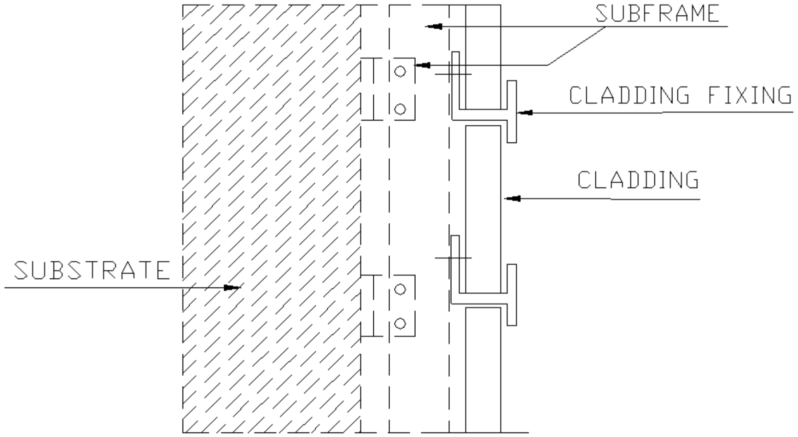
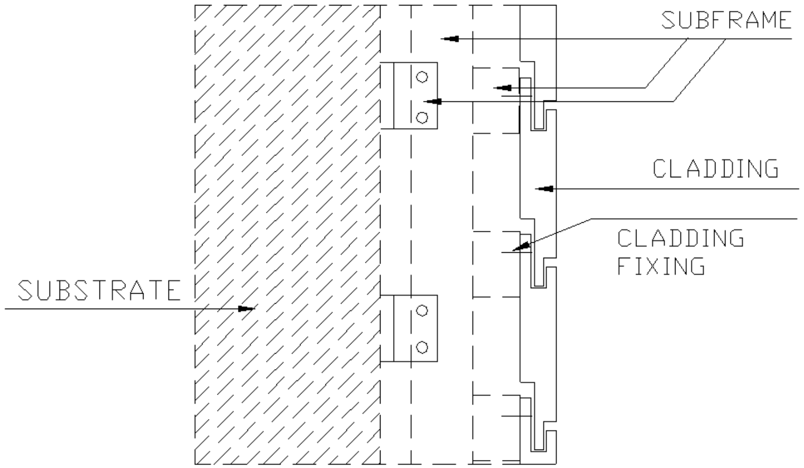
Type F - Cladding kit consisting of cladding elements mechanically fastened to the subframe by at least 4 metal clips or rails	Type D - Cladding kit consisting of cladding elements, integrated with adjacent elements by interlocking together at top and bottom with an overlap, fixed to the subframe by mechanical fixings positioned on the top edge and masked by the edge of the upper elements
 	

Table 2 – Tests on claddings (full size test rigs)

Test	**Test method *(EN, ISO, …)***	**Test samples *(dimensions – mm/ quantity)***		**Quantity**	**Remarks**	**Partner**
		According to test method	**Maximum permitted by the**			

Test	**Test method** ***(EN, ISO, …)***	**Test samples** ***(dimensions – mm/ quantity)***		**Quantity**	**Remarks**	**Partner**
			apparatus			
Single Burning Item (SBI)	EN 13823	1500 x 1000 + 1500 x 495 x (200 max)	1500 x 1000 + 1500 x 495 x (max 200)	3 + 3 (minimum)	Annex E (ETAG 034) includes precise, specific information about the SBI-Testing for cladding kits Asymmetrically composed cladding elements may have to be tested to reaction to fire on back side.	LNEC
Watertightness of joints *It seem the cladding is not watertight* *Because it has open joints. So, this test isn't applicable*	*EN 12865*	*Not defined*	*4200 (height) x 4800 (width) including rigid frame (see note 1)*	*One test specimen normally is sufficient (note 2)*	*Applicable to closed joints solutions. The dimensions of the test specimens shall be as large as necessary to be representative of the intended use.* *The joints of modules in the test specimen shall be representative, e.g. the same length per square meter as in reality.*	*LNEC (if required)*
Wind load resistance	ETAG 034	Not defined	4200 (height) x 4800 (width) including rigid frame (see note 1)	1+2 if necessary (note 2)	For family F a minimum surface cladding of 1,5 m^2 shall be tested. For family D, at least 3 x 3 elements shall be tested. See 0.	LNEC
Mechanical test	**ETAG 34**					
Type D				5		
Pull-through resistance of cladding (Figure 42~~Figure 42~~)				5		LNEC

Test	**Test method** *(EN, ISO, …)*	**Test samples** ***(dimensions – mm/ quantity)***		**Quantity**	**Remarks**	**Partner**
Resistance of grooved cladding element (Figure 43~~Figure 43~~)				5		LNEC
Pull-through resistance under shear loads (Figure 44~~Figure 44~~)				5		LNEC
Type F						
Resistance of metal clip (Figure 45~~Figure 45~~)				5		LNEC
Resistance to vertical load					One panel fixed in a concrete wall	LNEC
Resistance of brackets to vertical loads (Figure 46~~Figure 46~~)	ETAG 34, II			5		LNEC
Resistance of brackets to horizontal loads (Figure 47~~Figure 47~~)	ETAG 34, II			5		LNEC
Resistance to horizontal point loads	ETAG 34			1 panel element (2,6 x 0,5)	Test will be performed in the sample for wind load test (Figure 49~~Figure 49~~)	LNEC
Impact resistance Hard Body	ISO 7892:1988			1 panel element (2,6 x 0,5)	Test will be performed in the sample for wind load test (Figure 49~~Figure 49~~)	LNEC
Impact resistance Soft Body	ISO 7892:1988			1 panel element (2,6 x 0,5)	Test will be performed in the sample for wind load test (Figure 49~~Figure 49~~)	LNEC
Hygrothermal behavior – Resistance to thermal shock	ETAG 34		3,1 m x 2,0 m	1	Prototype in Figure 47~~Figure 47~~.	
Thermal resistance	EN ISO 6946: EN ISO 10211			0	By calculation.	LNEC

Note 1 – Test specimen frame

Shall be respected the following restrictions:

L ≥ 1100 mm and L ≤ 4800 mm;
H ≥ 1300 mm and H ≤ 4200 mm
Frame thickness between 50 mm and 150 mm

Greater sizes could be allowed but will require special works from the construction company.

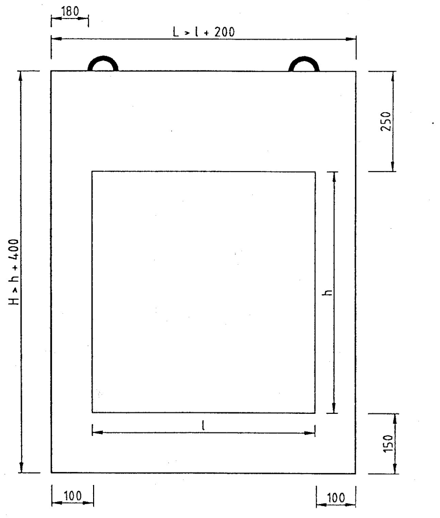


Figure 41 – Dimension of the test specimen support rigid frame

Note 2 – Usually one specimen representing the large size solutions is enough. If in the course of experimental evaluation some rupture occur those components should be replaced, for instance in the wind load test or impact test.

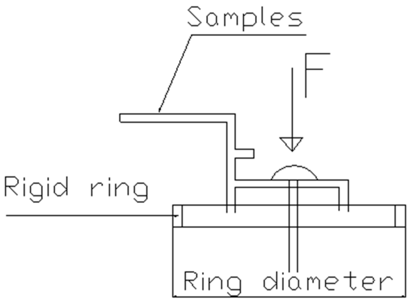


Figure 42 – Pull through test

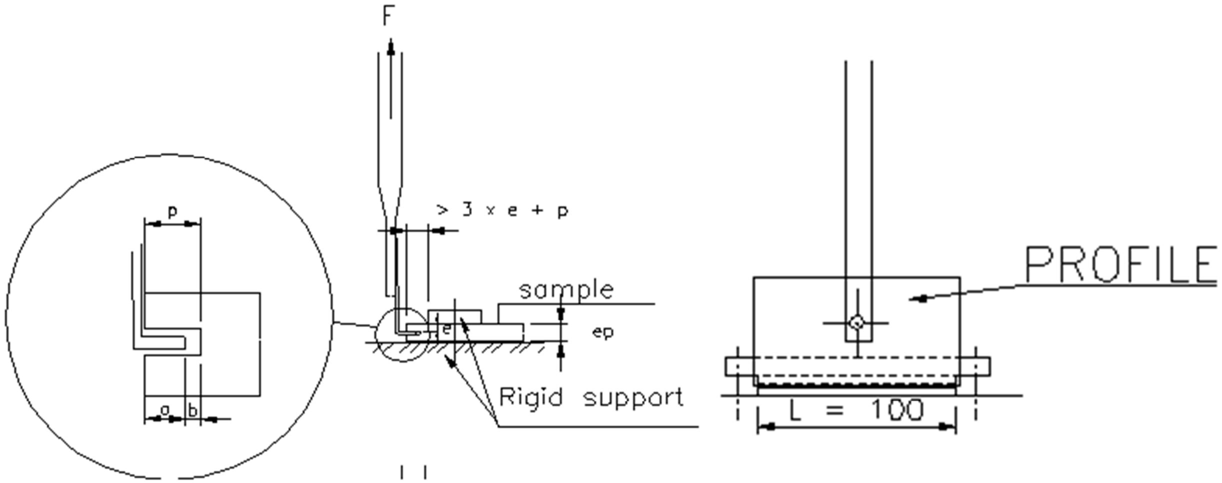
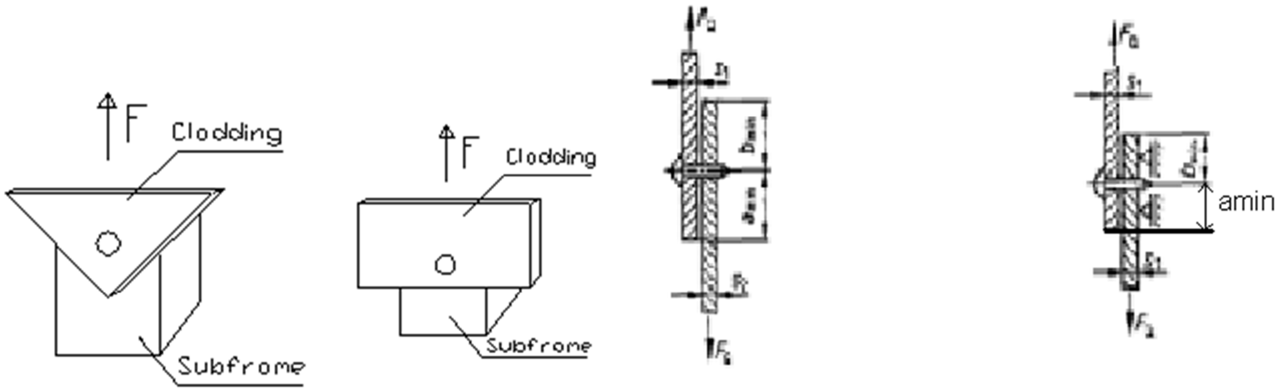


Figure 43 – Pull through of grooved element



F_Q: shear force; a_{min}: smallest intended edge distance of the cladding; b_{min}: smallest intended edge distance of the subframe; s_1: thickness of the cladding; s_2: thickness of the subframe

Figure 44 - Pull-through resistance under shear loads

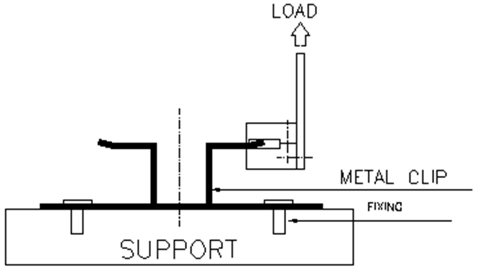


Figure 45 - Resistance of metal clip

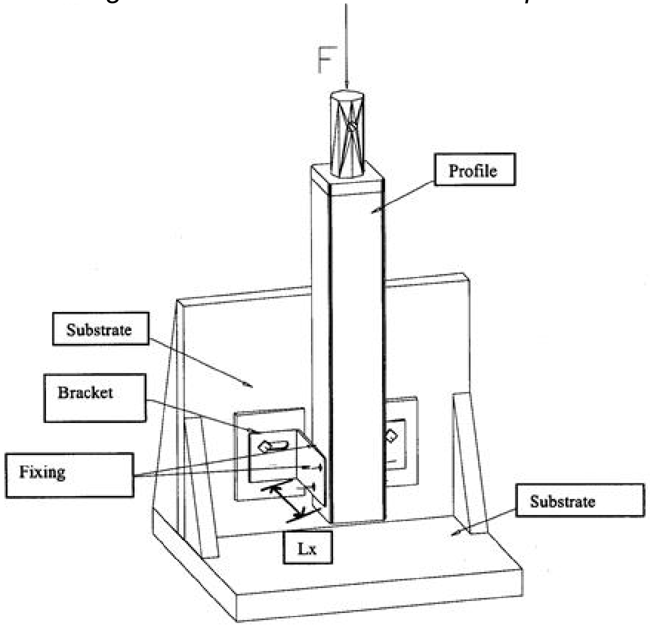


Figure 46 - Resistance of brackets to vertical loads

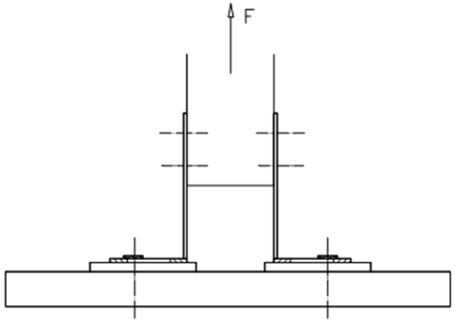


Figure 47 - Resistance of brackets to horizontal loads

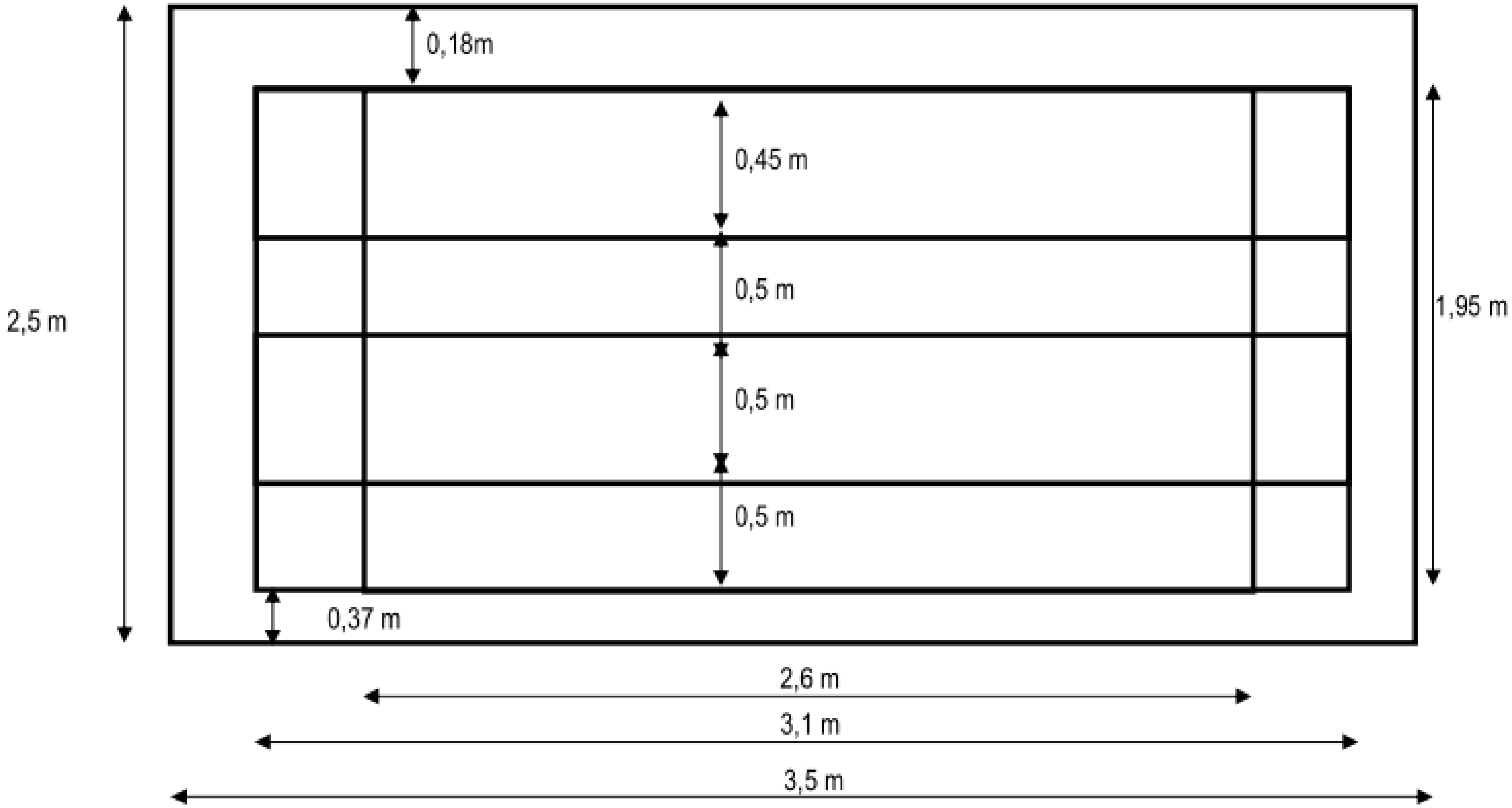


Figure 48 – Resistance to thermal shock

MOUNTING AND FIXING PROVISIONS FOR THE SBI TEST

The specimen shall be installed on a substrate in accordance with standard EN 13238:

All components which form part of the kit (e.g. breather membranes and cavity barriers) shall be included in a representative fashion in the test specimen.

An air space is always provided under cladding in accordance with the manufacturer’s instructions (minimum of 20 mm). The bottom and top edges of the specimen shall also remain opened. If mineral wool insulation layer is planned in end-use situation of the kit, a 50 mm thick insulation product made of mineral wool according to EN 13162, with a density of 30 to 70 kg/m3, shall be installed between frame and substrate. For other insulation materials, different conditions can be used for testing (e.g. maximum and/or minimum thicknesses, maximum and/or minimum density, unless proven otherwise).

When the kit tested presents a horizontal joint, it shall be tested with a horizontal joint in the long wing at a height of 500 mm from the bottom edge of the specimen and when the kit tested presents a vertical joint, it shall be tested with a vertical joint in the long wing at a distance of 200 mm from the corner line, in accordance with the following Figure E 1. In the areas A, B, C, D and E, it is possible to have other vertical and/or horizontal joints between cladding element, if their size is not big enough.

In the internal vertical angle, no profile shall be used and the cladding elements create a vertical close joint.

Note: Asymmetrically composed cladding products are tested free-hanging arrangement in such a way that the rear of the product is exposed to the flame (see paragraph 5.2.2).

Note: Test specimen dimensions to be confirmed (small adjustments) before test preparation

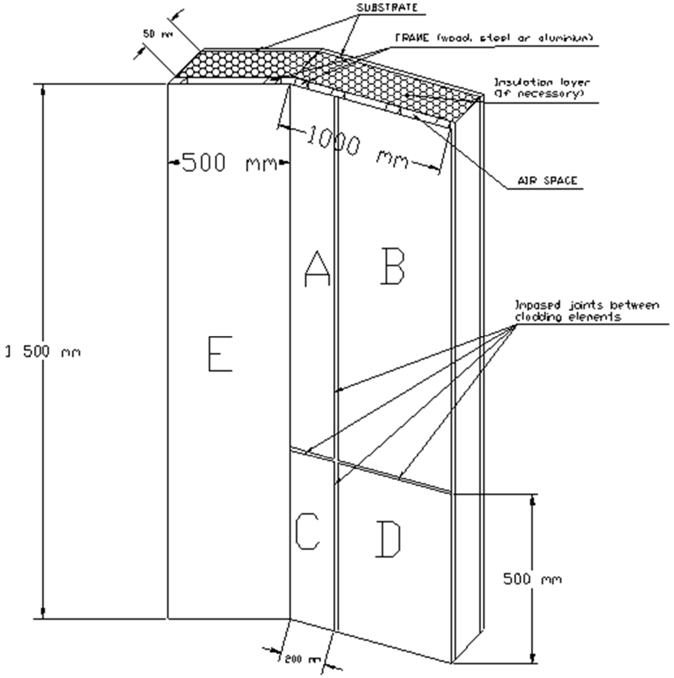


Figure E 1 - Example of installation

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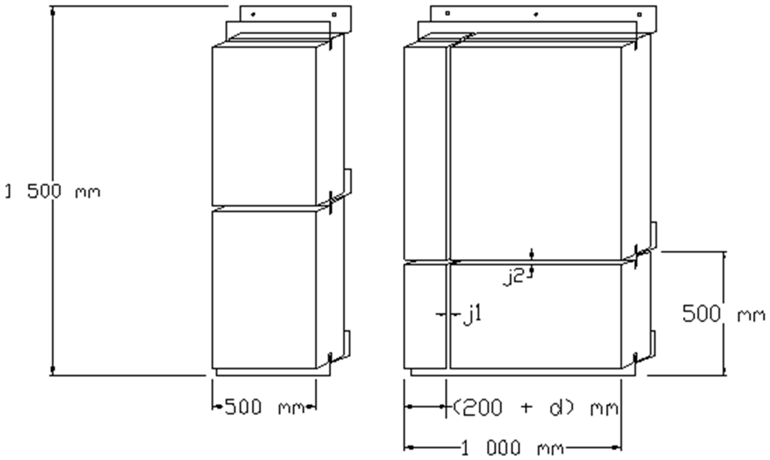
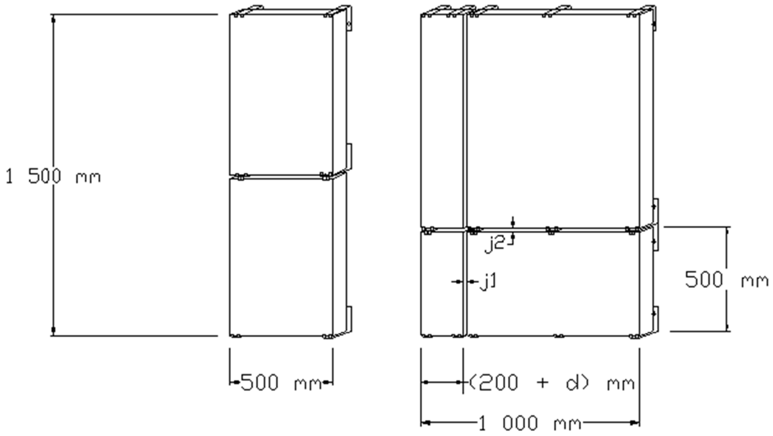

1 500 mm
500 mm
j2
j1
500 mm
(200 + d) mm
1 000 mm
</td>
<td>

1 500 mm
500 mm
j2
j1
500 mm
(200 + d) mm
1 000 mm
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</table>

Mounting for the wind load test

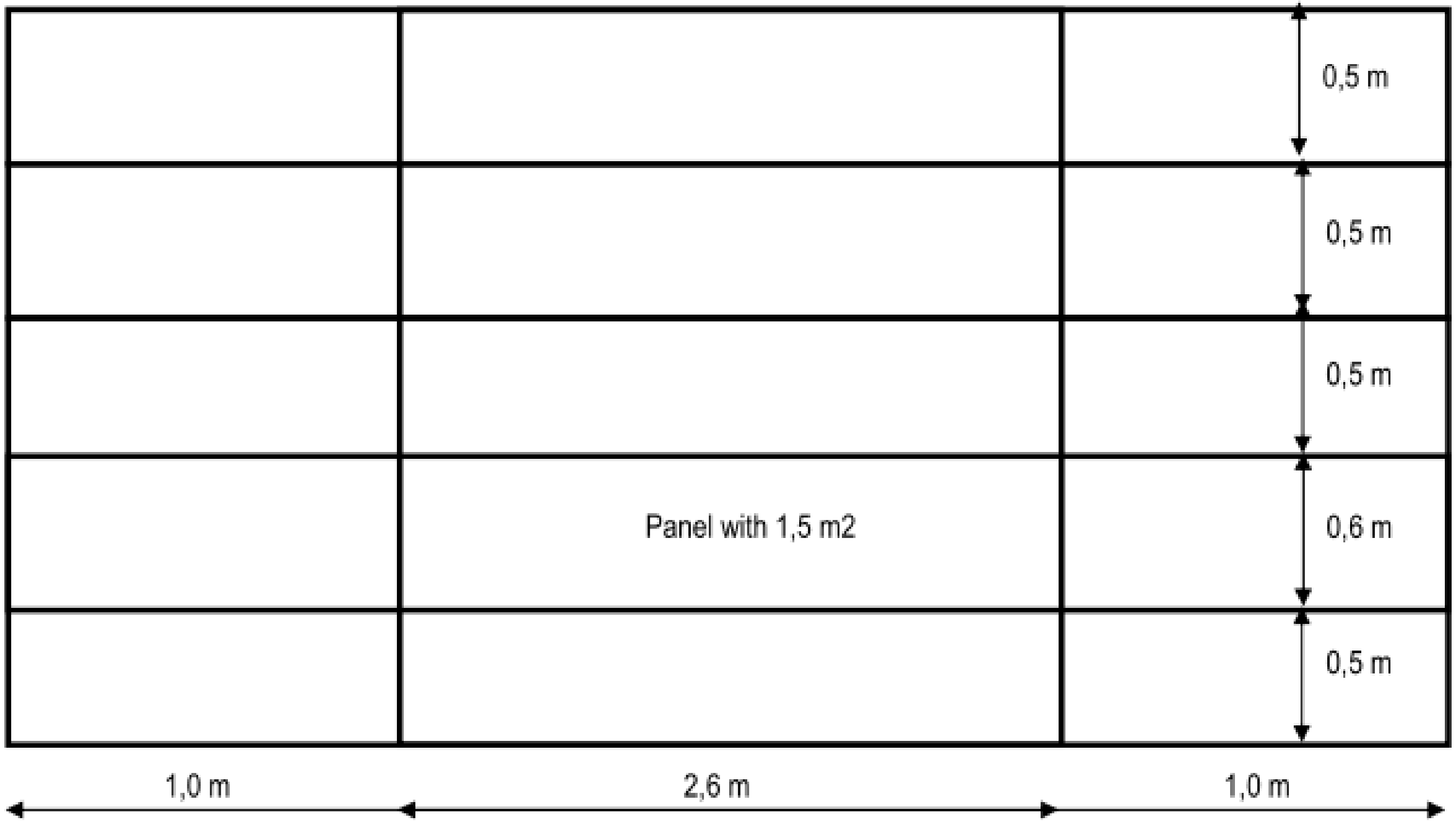
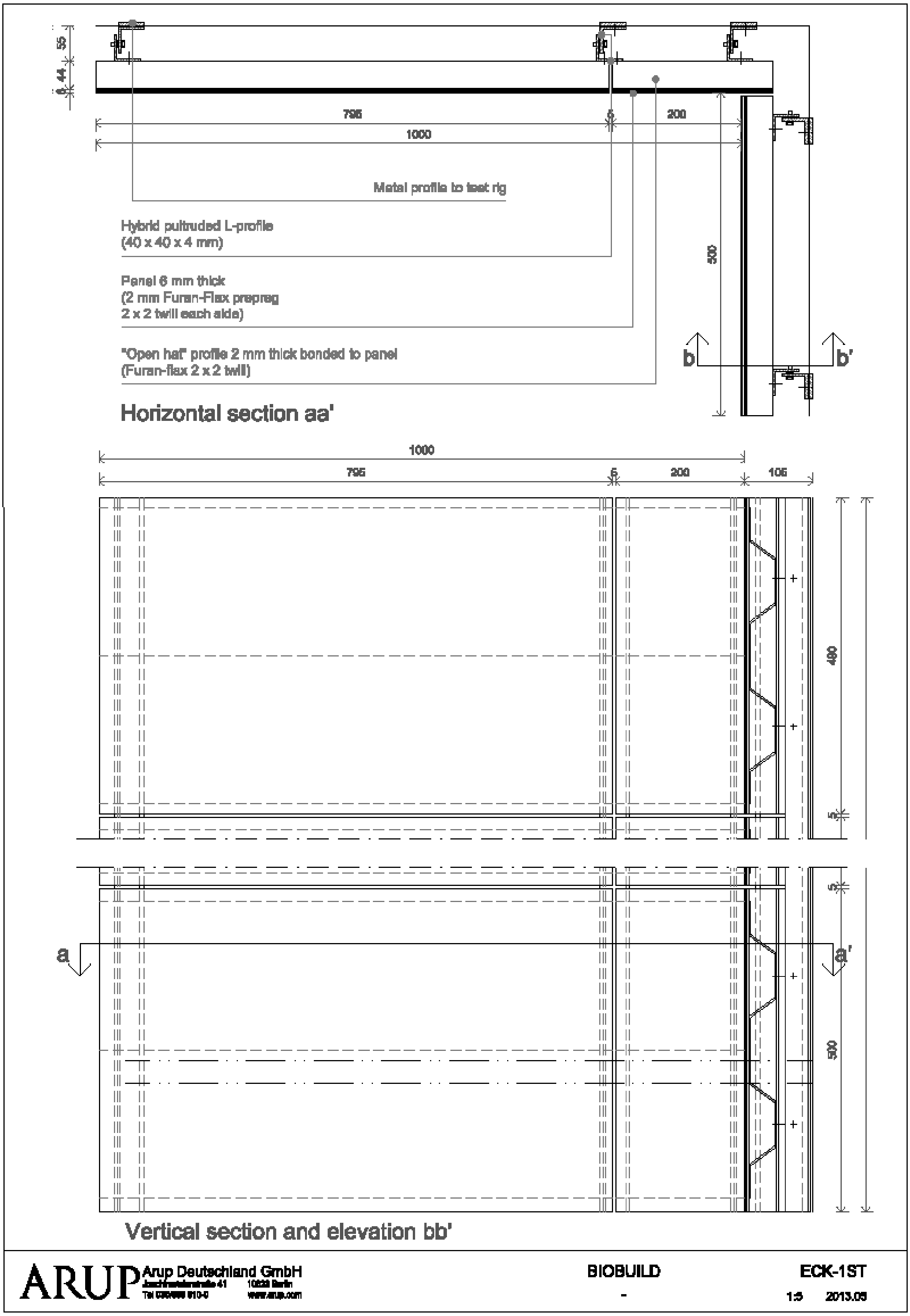
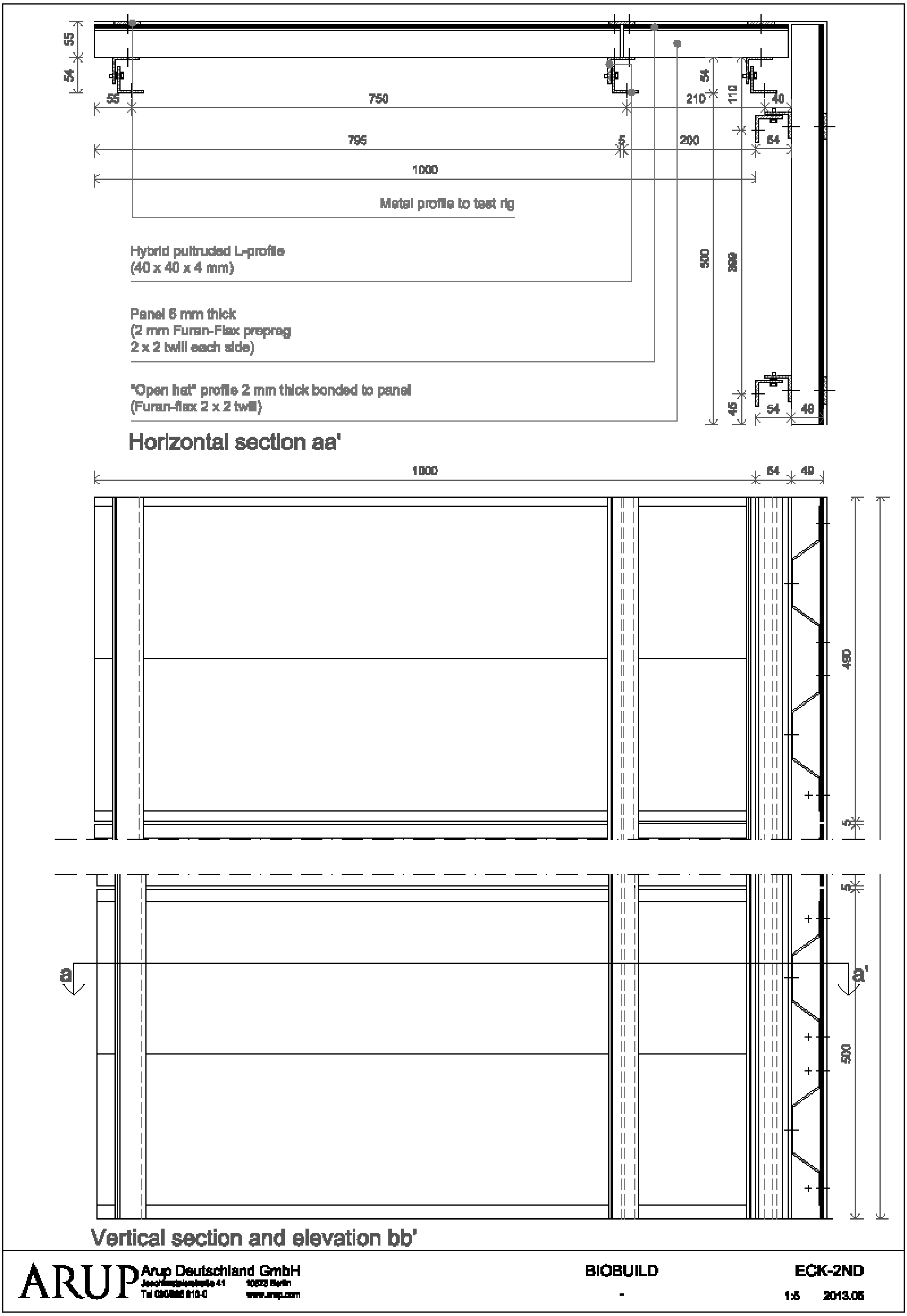


Figure 49 – Sample for wind load test

ANNEX E – External cladding kit (ECK) test specimen for SBI


55
6 44
795
5
200
1000
Metal profile to test rig
Hybrid pultruded L-profile
(40 x 40 x 4 mm)
Panel 6 mm thick
(2 mm Furan-Flax prepreg
2 x 2 twill each side)
"Open hat" profile 2 mm thick bonded to panel
(Furan-flax 2 x 2 twill)
500
b
b'
Horizontal section aa'
1000
795
5
200
105
490
5
5
500
a
a'
Vertical section and elevation bb'
ARUP
Arup Deutschland GmbH
www.arup.com
BIOBUILD
-
ECK-1ST
1:5
2013.05


55
54
55
750
210
54
110
40
795
5
200
54
1000
Metal profile to test rig
Hybrid pultruded L-profile
(40 x 40 x 4 mm)
Panel 6 mm thick
(2 mm Furan-Flax prepreg
2 x 2 twill each side)
"Open hat" profile 2 mm thick bonded to panel
(Furan-flax 2 x 2 twill)
500
389
45
54
49
Horizontal section aa'
1000
54
49
450
5
5
a
a'
500
Vertical section and elevation bb'
ARUP
Arup Deutschland GmbH
www.arup.com
BIOBUILD
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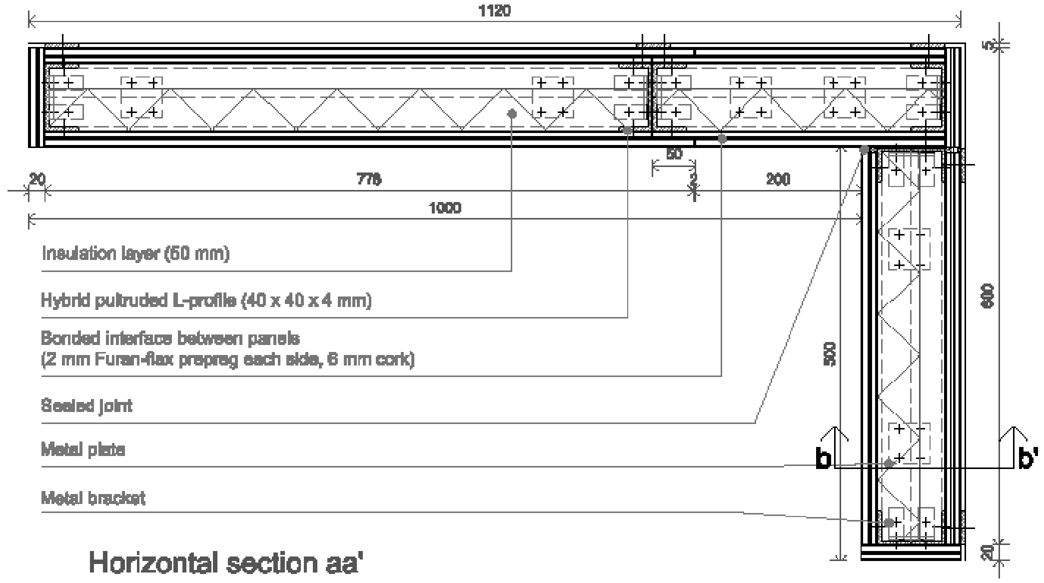
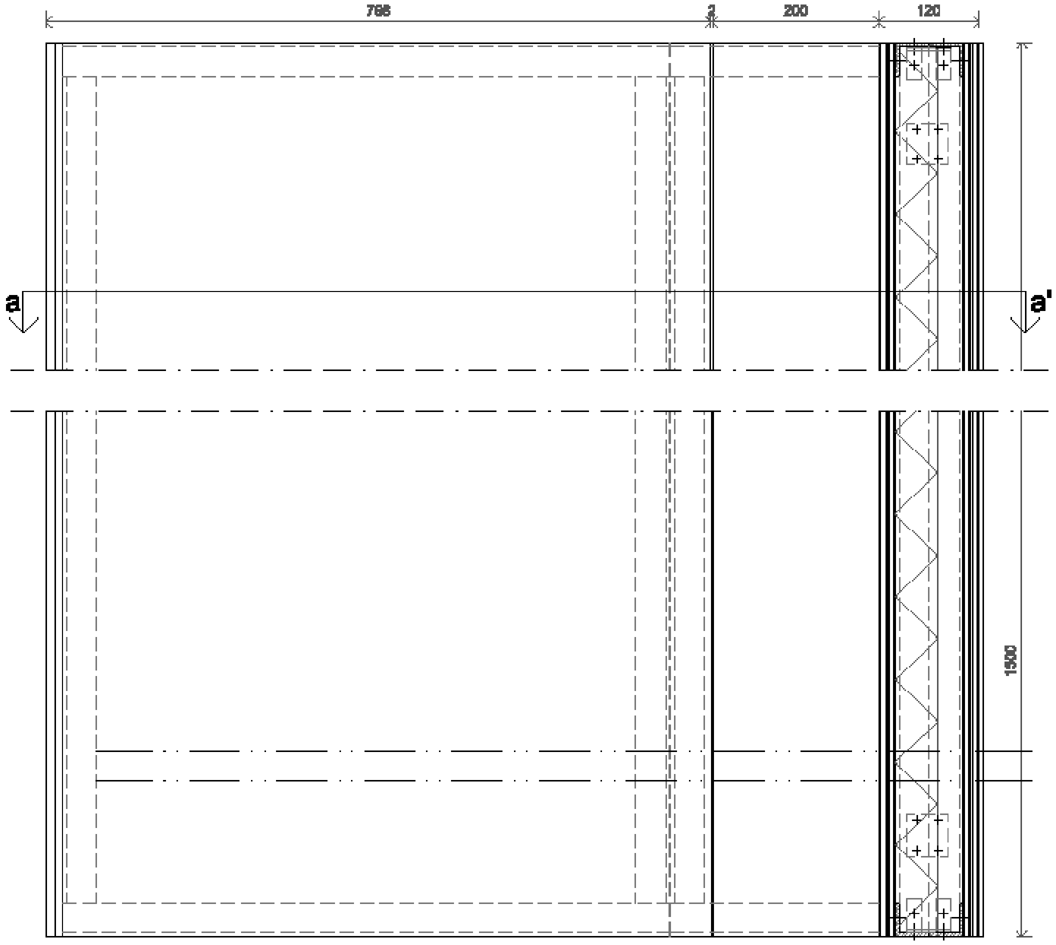
ECK-2ND
1:5
2013.05

ANNEX F – Internal partition kit (IPK) test specimen for SBI



Horizontal section aa'



Vertical section and elevation bb'

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Joachimsthaler Straße 41 10623 Berlin
Tel 030/885 910-0 www.arup.com

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IPK-1ST
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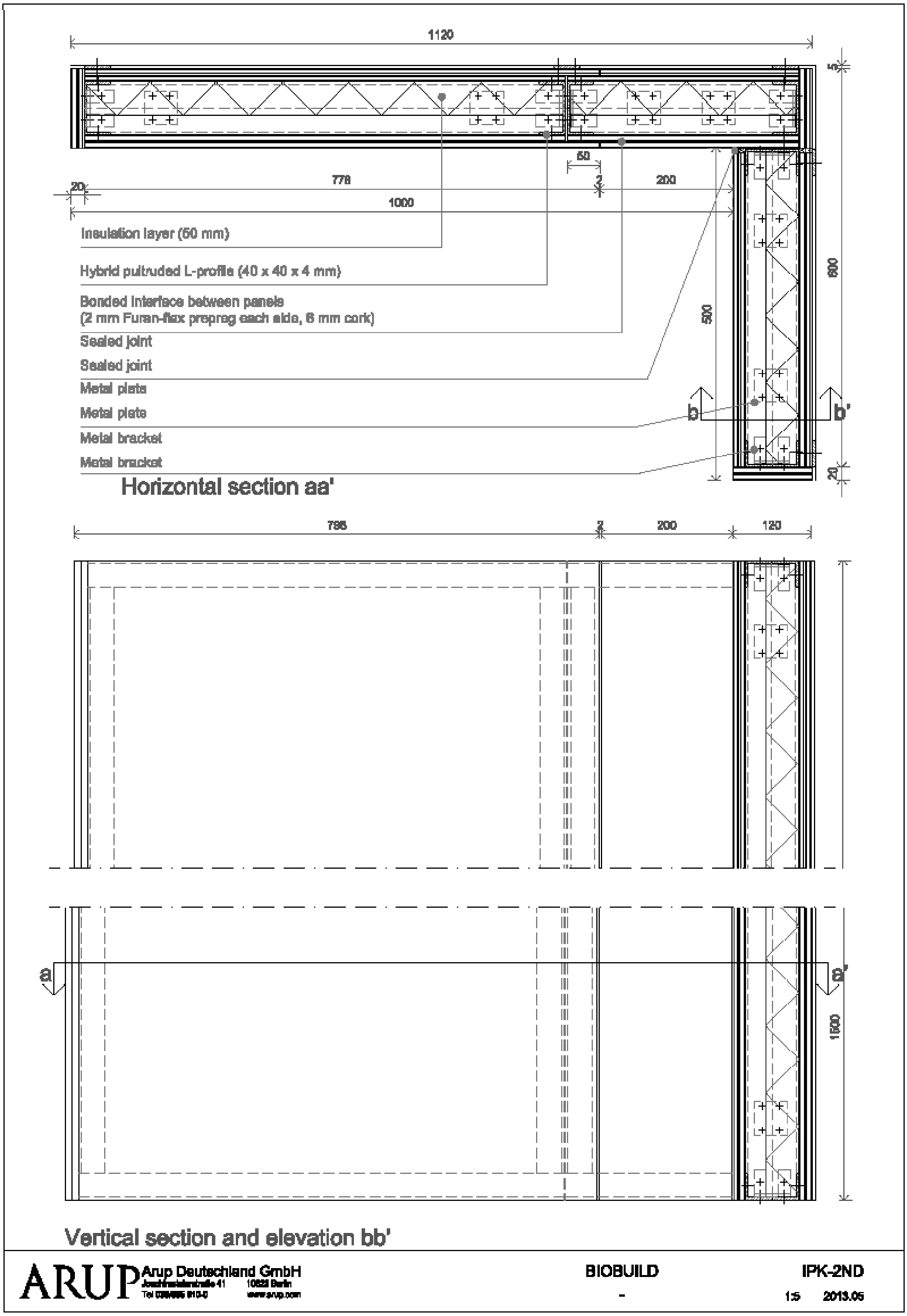
1120
5
50
778
2
200
20
1000
500
600
20
Insulation layer (50 mm)
Hybrid pultruded L-profile (40 x 40 x 4 mm)
Bonded interface between panels
(2 mm Furan-flax prepreg each side, 6 mm cork)
Sealed joint
Sealed joint
Metal plate
Metal plate
Metal bracket
Metal bracket
b
b'
Horizontal section aa'
795
2
200
120
a
a'
1500
Vertical section and elevation bb'
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Arup Deutschland GmbH
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IPK-2ND
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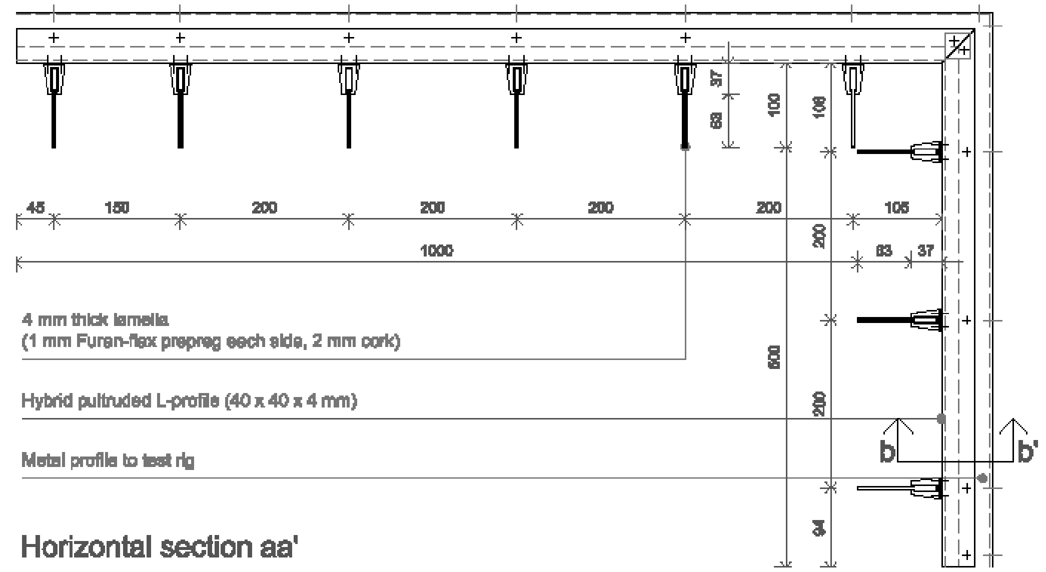
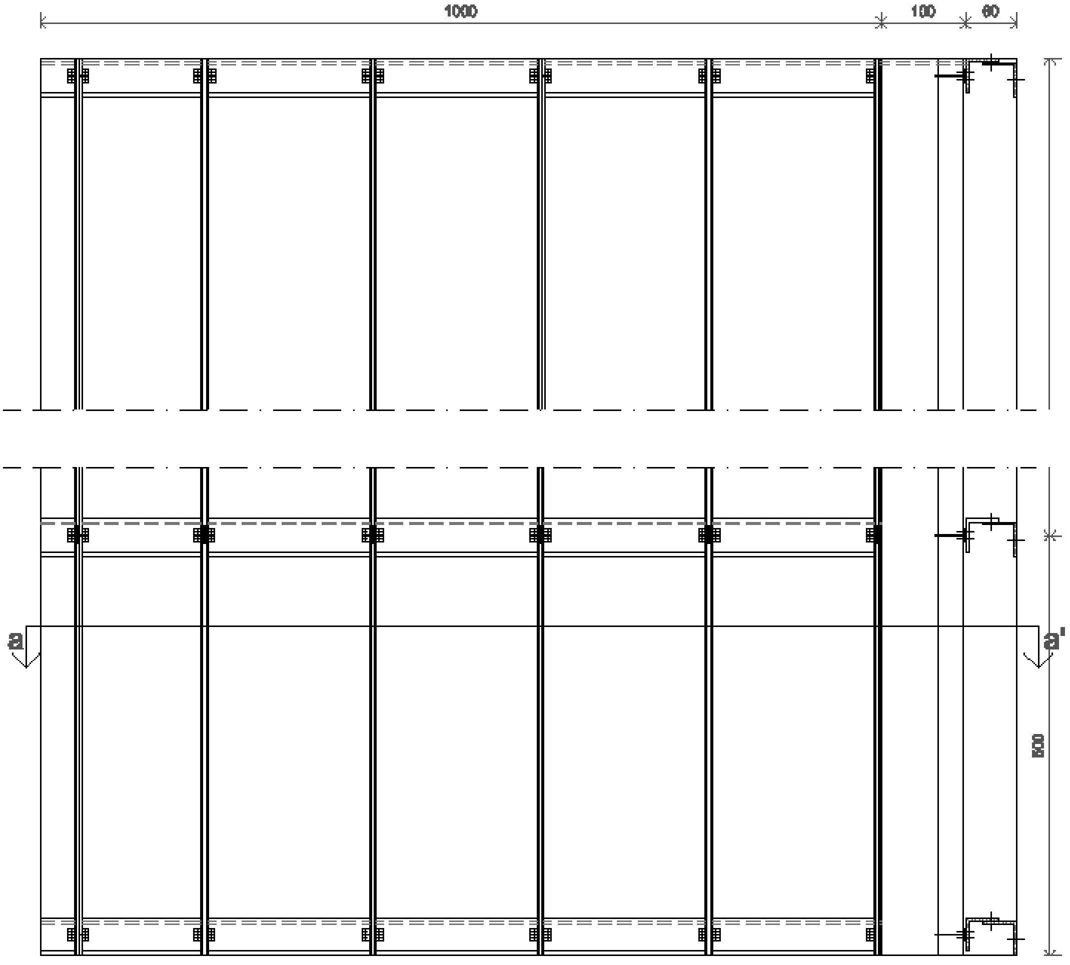
ANNEX G – External cladding kit (SCK) test specimen for SBI



Horizontal section aa'



Vertical section and elevation bb'

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SCK-1ST
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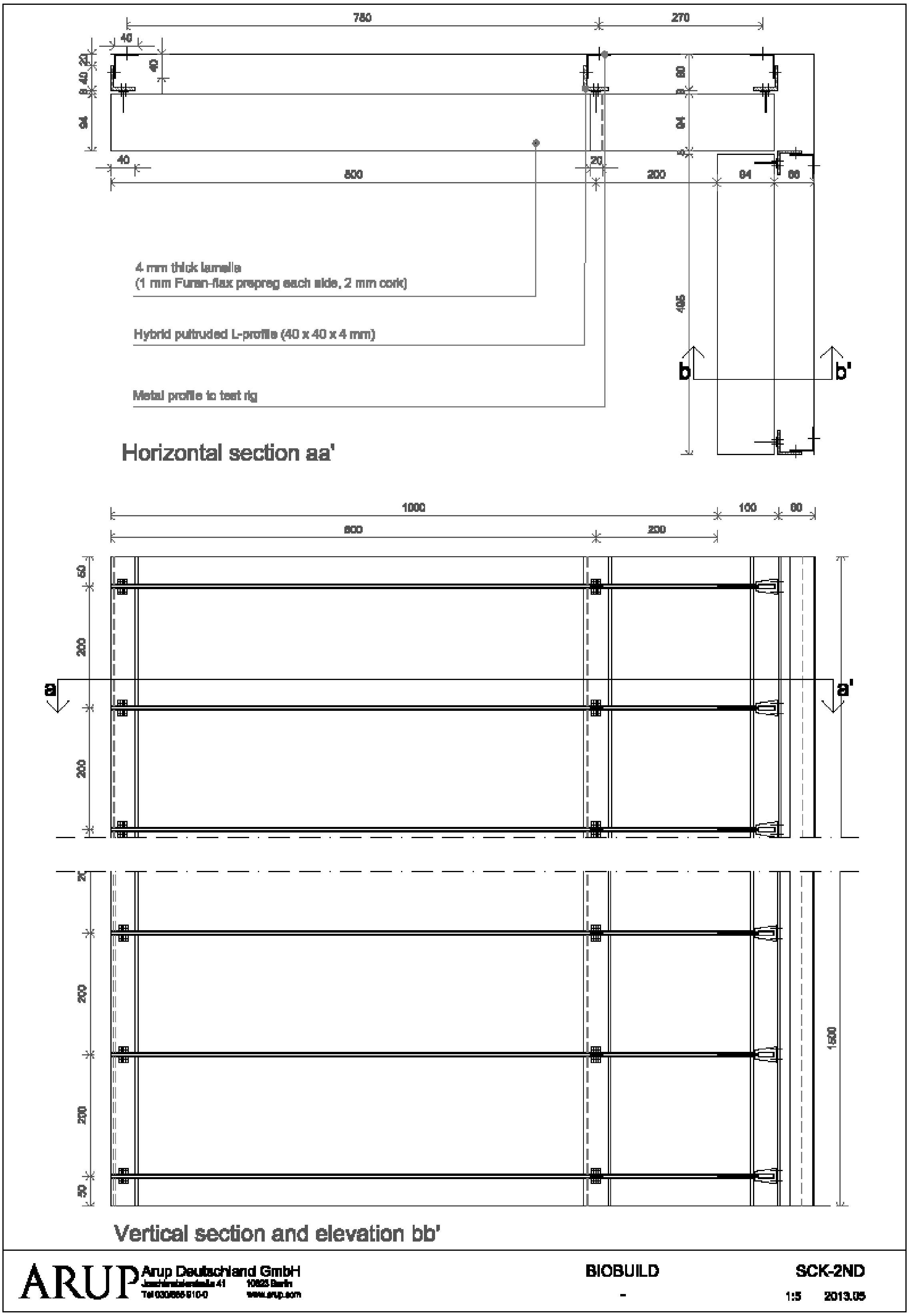
780
270
40
20
40
8
94
40
40
20
800
200
94
66
495
b
b'
4 mm thick lamella
(1 mm Furan-flax prepreg each side, 2 mm cork)
Hybrid pultruded L-profile (40 x 40 x 4 mm)
Metal profile to test rig
Horizontal section aa'
1000
100
60
800
200
50
200
a
a'
200
1500
Vertical section and elevation bb'
ARUP
Arup Deutschland GmbH
Joachimstalerstraße 41
10623 Berlin
Tel 030/885 910-0
www.arup.com
BIOBUILD
-
SCK-2ND
1:5
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