SUSTAINABLE COMPOSITES FOR CONSTRUCTION: A REVIEW

Blai López-Rius[1*], Anabel Crespo[2] and Arsenio Navarro[3]

[1] Construction and Renewable Energies Group, AIMPLAS, Valencia, Spain, blopez@aimplas.es
[2] Technologies Manager, acrespo@aimplas.es
[3] Construction and Renewable Energies Group, AIMPLAS, Valencia, Spain, anavarro@aimplas.es
AIMPLAS, Valencia, Spain, https://www.aimplas.es/

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ABSTRACT

The certainty of global warming and, consequently, climate change urges for planners' actions to create low carbon cities and, therefore, reduce the carbon emissions. One of the methods recently adopted by the construction industry is green construction or sustainable construction. To make a construction sustainable it should be minimized the waste of materials by design, proper selection of quantity and quality of materials, and application of sustainable materials. Furthermore, to reduce the impact on environment and energy consumption, the use of reusable or recyclable at the end-of-life materials should be enhanced.

In this paper, the importance of sustainable construction using innovative composites materials to overall sustainable development is underscored. It is also highlighted the fact that composites materials have an important role in the attainment of sustainable construction. In this respect, the route to sustainable construction was identified to be through improved sustainable composites materials coming from natural resources or from agro-waste industry and enhancing building for disassembly and deconstruction for end-of-life reuse and recycling.

The scientific community is making great efforts to develop sustainable composites for the construction sector, developing matrices, reinforcements, fillers, and adhesives. However, it is necessary that these developments end up being commercial products. With the increasing availability and affordability of sustainable building materials, a sustainable construction sector will be a reality.

1 INTRODUCTION

The certainty of global warming and, consequently, climate change urges for planners' actions to create low carbon cities and, therefore, reduce carbon emissions. Sustainability has become a necessary feature in the construction sector. As reflected in Directive 2012/27 / EU on energy efficiency, the construction sector, buildings, are responsible for 40% of final energy consumption in the European Union and approximately 30% of emissions into the atmosphere, or what is the same, 40% of carbon emissions, so its reduction is very important in order to mitigate climate change and its consequences.

One of the methods recently adopted by the construction industry is green construction or sustainable construction. To make a construction sustainable it should be minimized the waste of materials by design, proper selection of quantity and quality of materials, and application of sustainable materials. A sustainable material is considered a material that does not deplete non-renewable (natural resources) and whose use has no adverse impact on the environment [1]. Furthermore, to reduce the impact on environment and energy consumption, the use of reusable or recyclable at the end-of-life materials should be enhanced.

Energy in buildings can be categorized into two types: firstly, by energy for the Maintenance/servicing of a building during its useful life, namely operational energy (O.E.) and, secondly, by energy capital that goes into production of a building using various building materials, named embodied energy (E.E.). Embodied energy of buildings can vary over wide limits depending upon the choice of building materials and building techniques. Generally, the materials used for the structure of buildings represent more than 50% of the embodied energy in the building. In this sense, the use of alternative materials, such as bio-based composites materials or materials incorporating waste

materials. In addition, recycling building materials is also essential to reduce the embodied energy in the building [2].

2 BIO-BASED COMPOSITES

In the last decade there has been a concerted effort to migrate fiber reinforced composites (FRC) into the construction industry for use in primary load bearing applications although the number of primary structural applications of FRCs in construction remains relatively low. However, sustainability become increasingly important to material choice and bio-based reinforced composite materials could be at an advantage over traditional materials. A bio composite is a material composed of two or more distinct constituent materials (one being naturally derived) which are combined to yield a new material with improved performance over individual constituent materials. In terms of the reinforcement, this could include plant fibres such as cotton, flax, hemp kenaf, jute, and sisal. Matrices may be polymers, ideally derived from renewable resources such as vegetable oils or starches. Natural fibres have many advantages over synthetic ones; no harm to the environment, enhanced energy recovery and biodegradability, low density, high toughness, acceptable specific strength, reduced dermal and respiratory irritation, low cost, renewable resources [3]. However, moisture absorption is generally high and impact strength is relatively low, so it is necessary to work on fiber surface treatments to improve interaction between fibre and matrix enhancing mechanical properties of the composite [4].

AIMPLAS has been developing bio-based composites in projects such as ECOXY (Bio-based, recyclable, reshapable & repairable (3R) fiber reinforced thermoset composites). In the framework of ECOXY [5] project, a window profile has been designed, developed, and obtained by pultrusion process, using flax fibres and bio-based epoxy resin.

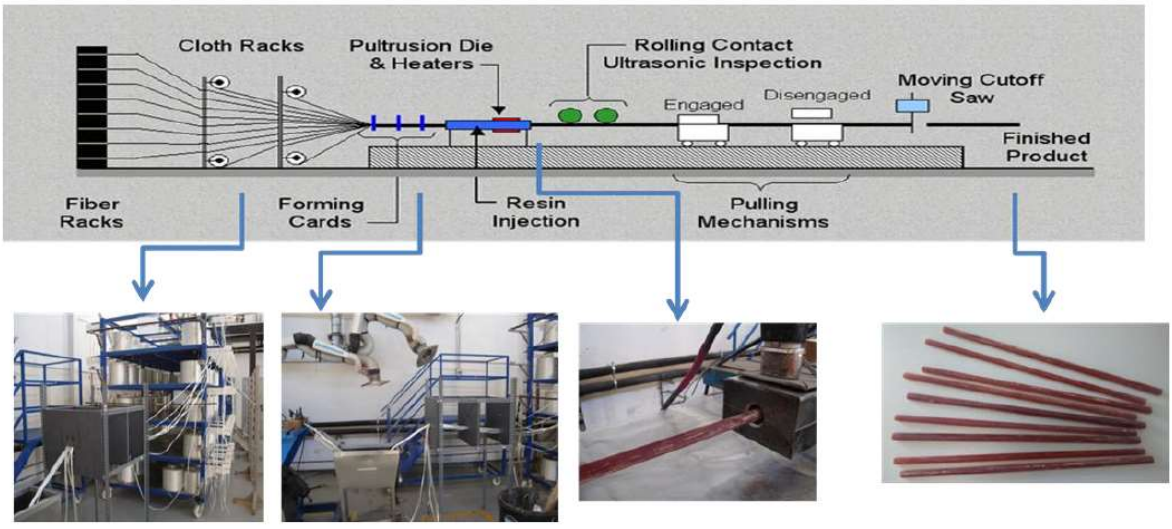

Figure 1. Pultrusion line elements on ECOXY project.

For the construction sector, where corrosion resistance is a main issue, glass fibre-reinforced polymers composite (GFRP) rebars have shown a good corrosion resistance. However, current composites cannot be easily bent, are not weldable and are difficult to recycle. For these reasons, the materials that have been developed in ECOXY have been validated in the construction sector (as proof of concept) using their today's relevant standards and applicable certifications, obtaining a window profile for the construction sector as a demonstrator.

Mainly, ECOXY composites have been manufactured by pultrusion process but, in contrast to current materials, a bio-based epoxy resin with 3R properties (reshapable, repairable and recyclable) has been used.

These new advanced functionalities have been achieved using cutting-edge chemistry. Commonly used epoxy resin systems are reacted with curing agents, known as hardeners, to obtain infusible and unreprocessable thermoset matrices. These compounds are based on reversible covalent bonds that

under certain conditions (temperature and pressure) can rearrange while keeping the crosslink density. This feature gives the materials a new set of properties (3R), while keeping the mechanical properties unaltered at operational conditions.

Figure 2. Window concept demonstrator on ECOXY project.

Besides, ECOXY has used and has taken benefit from the advantages of using natural and/or bio-based fibres, such as the low specific weight which results in a higher specific strength and stiffness than glass, their renewable nature, and the fact that they are producible with low investment at low cost. As a reference, flax rovings and fabrics, specially designed to have a good interaction with the new matrix, have been developed. In addition, the innovative route of implementing bio-based polylactic acid (PLA) yarns as reinforcement for composites has been explored.

3 COMPOSITES FROM AGRO-WASTE

A large demand has been placed on the building material industry due to the increasing population that causes a chronic shortage of building materials. On the other hand, disposal of solid waste generated from agricultural and industrial production activity is another serious problem in developing countries. Reuse of such wastes as a sustainable construction material appears to be viable solution not only to pollution problem but also to the problem of the land-filling and high cost of building materials. Different studies have shown that various agro-waste materials can be used in different proportions to produce different building materials and composites such as particle boards and thermal insulated wall and ceiling panels obtaining promising results comparing to petrol-based materials. Moreover, wood-polymer composites (WPC) increasingly gain in popularity in the building industry and the manufacturing of WPC coming from agro-waste might be a reality in short.

Mycelium based bio composites are another research line with promising results [6]. In this case, the fibrous network of mycelium (the vegetative part of fungi) is employed to produce sustainable alternatives for synthetic foams for thermal insulation in the construction sector. Considering the fast-growing rate of mycelium, its limited irrigation requirements, its ability to consume and utilize plant

waste, and its unique mechanical and aesthetic properties, its implementation in industrial value chains can provide an essential solution to improve the lifecycle patterns of future construction products although there exists some challenge regarding their durability and mechanical properties.

AIMPLAS has been working on the development of composites from agro-waste in projects such as BASAJAUN (Sustainable wood construction for rural development and urban transformation). In the framework of BASAJAUN project, a biocomposite curtain wall for a façade system has been designed, developed and obtained by pultrusion process, using basalt fibres, bio-based polyester resin and agro-waste materials.

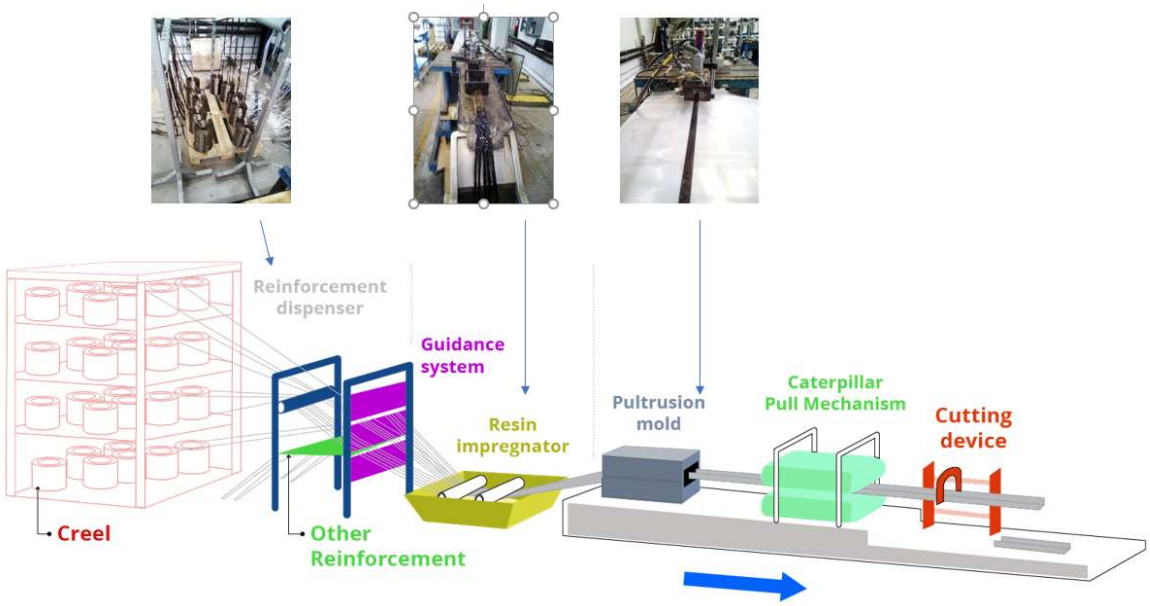

Figure 3. Pultrusion line elements on BASAJAUN project.

The façade system is a non-structural building envelope made of bio-based composites. Through safe off-site production and easy on-site assembly, they provide flexible solutions customize as opaque or transparent wall elements.

Modern wooden houses convince with high living comfort, extremely short construction times through off-site prefabrication, and low environmental impact of the nature-based building materials. However, façade systems often lack design for disassembly needed for circular economy value chains and use mainly energy intensive materials such as aluminium.

An alternative to such conventional systems is the BASAJAUN [7] bio-composite multi-layer curtain-wall façade system. Besides being a high-quality façade system, the main assets are due to off-site prefabrication techniques that allow for both easy and safe on-site assembly and, at the end of the building use cycle, disassembly of the biobased components for further use in closed circular economy material loops.

Figure 4. Images of the bio-based profile and the façade fire test (Source: Focchi Group).

A bio-composite material is used for the façade profiles replacing energy intensive and heat conducting aluminum. The fixing substructure offers aesthetic customization options for the exterior building finish allowing for wooden lamellas, porcelain tiles, fiber cement or other types of panels for external cladding. This allows both high customer satisfaction and a cost-efficient production process of a one-type-fits-all substructure. After successful fire resistance tests, the façade is applied to the BASAJAUN demo building in southern France.

4 DISASSEMBLY AND RECYCLABILITY

Construction waste management has become extremely important due to stricter disposal and landfill regulations, and a lesser number of available landfills. A sustainable project has to be delivered by an integrated, planned and well managed construction process. Deconstruction is the process of dismantling a building to salvage its materials for recycle or reuse. Materials used for constructions have a relevant importance when deconstruction phase arrives. Innovative thermoplastic reinforced composites based on recycled polymers such as PET have been developed to obtain new thermoplastic pultrusion parts that might be applied in the construction sector. On the other hand, debondable adhesives ae being developed to enhance disassembly in the construction sector. These adhesives allow the separation of composites parts to facilitate the reuse or recyclability of the part at their end of life.

AIMPLAS has been working on the development of disassembly systems and recyclable composites in projects such as ECOGLUE (Removable eco-adhesives for use in footwear, construction and transportation). In the framework of ECOGLUE [8] project, a removable or reversible bio-based adhesive has been developed for the construction sector.

The increase in circular products from the assembly of different materials with a low carbon footprint and compatible with recycling, makes adhesives play a fundamental role in their development. At present, these adhesives have a great dependence on fossil resources to obtain them, so it is necessary to investigate the development of said adhesives from renewable resources, all without detriment to their benefits. On the other hand, the high resistance and durability that these adhesives give to the joints make the recycling and recovery process of the final product of its useful life difficult.

For this reason, the main objectives of the ECOGLUE project were, on the one hand, the development of state-of-the-art bio-adhesives based on raw materials from renewable sources with a low carbon footprint and features like conventional ones. On the other hand, the development of reversible/removable eco-adhesive formulations, so that they are compatible with recycling and repair at the end of the product's useful life, contributing to the development of circular products with low environmental impact.

Traditionally, the debonding of structural adhesive joints is based primarily on methods of destroying the joint by mechanical, thermal or chemical degradation of the adhesive, cutting the joint, or a combination of these methods. These alternatives can damage or even destroy the substrates.

In this context, ECOGLUE has developed removable or reversible bio-epoxy based adhesives for the construction sector. Work has been done in parallel to obtain two types of formulation. A formulation based on the addition of additives that favour the preparation of a detachable adhesive, and another reversible formulation focused on the synthesis and use of reversible hardeners. In the latter case, disassembly is possible, but also re-bonding once the external stimulus has disappeared, favouring the reuse of the same adhesive (Figure 5).

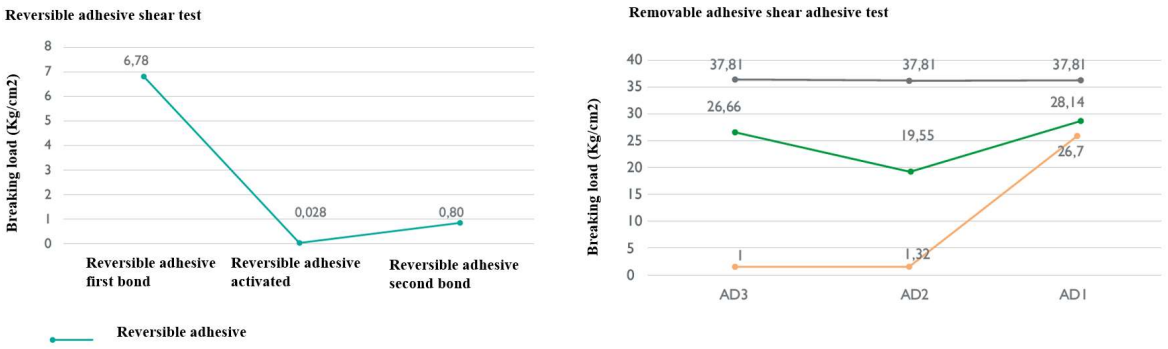

Figure 5. Results obtained with the adhesive obtained.

Regarding the application of external stimuli, it had worked mainly with the heating of the adhesive through different systems: convection, Joule effect, electromagnetic induction, and electromagnetic radiation (microwaves, MW).

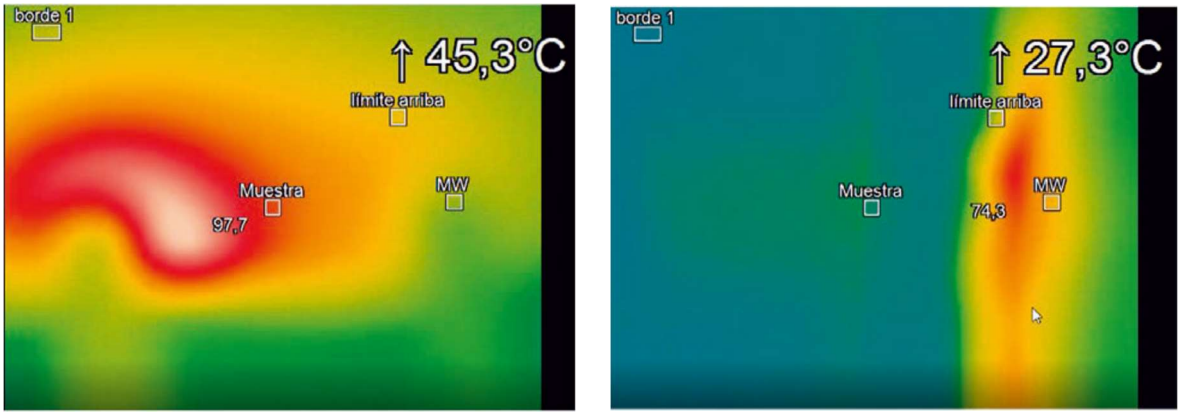

Figure 6. Thermographic samples of the union.

The results obtained have been promising since they show that it is possible to design a customized adhesive by modifying its adhesion properties in the face of an external stimulus and therefore controlling the adhesion force on demand based on the requirements defined for each application.

3 CONCLUSIONS

Clearly, there are eco-friendly building materials becoming available. Development of new technologies means that bio-based composites coming from natural resources or from waste materials are becoming easier and easier to produce, at a higher quality with an affordable cost. Moreover, disassembly and recyclability are being assessed from the beginning, selecting building materials which can be reused or recycled at their end of life.

The scientific community has made and is making great efforts to develop sustainable composites for the construction sector, developing matrices (bio-based, reprocessable, repairable, recyclable resins, etc.), reinforcements (natural fibers, thermoplastics, etc.), fillers (bio-based, from agro-waste, etc.), and adhesives (bio-based, removable, reversible, etc.).

However, it is necessary that these developments end up being commercial products. With the increasing availability and affordability of sustainable building materials, a sustainable construction sector will be a reality.

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