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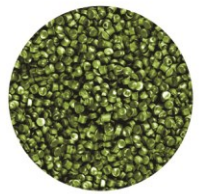
## Handbook Guidelines

for transferring the CEPLAFIB results  
to other regions and sectors



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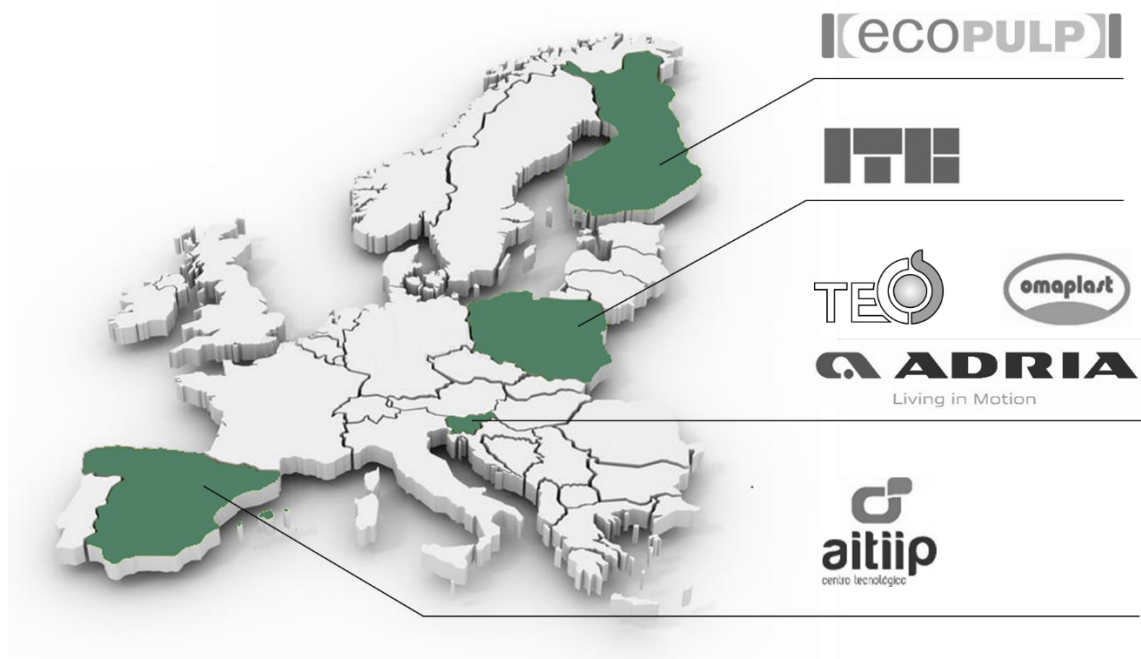
## 1. Introduction

Plant fiber reinforced polymer matrix composites (NFPCs) are currently widely used in various areas, especially in the automotive, aviation and shipbuilding industries <sup>1</sup>. Plant fiber reinforcement has replaced fiberglass <sup>2</sup>. Plant fibers have been recognized for their biodegradability, renewable sources, low density combined with high strength and resilience, low cost, and neutrality to humans and tools <sup>3</sup>. NFPC composites are also used in the construction sector. They are used for producing a wide range of profiles, mainly planks for constructing terrace floors, facade claddings, platforms, promenades, as well as landscaping elements <sup>4</sup>. NFPCs composites use fibers extracted from various species of trees, grass, and crops as reinforcement, both from virgin raw material and from waste material generated during processing. Sources of fiber include both hard and soft plant tissues - wood, stems, seeds, leaves, seeds, fruits, phloem, husks, and shells <sup>3,4</sup>. Plant fibers are lignocellulosic structures composed mainly of cellulose ( $\alpha$ -cellulose), hemicellulose, and lignin. They also contain a small amount of pectins, waxes, tannins and inorganic salts <sup>5</sup>. The chemical composition of individual fibers varies, depending on the plant species, its age, but also on its growing conditions, including climate and soil conditions, and has a significant impact <sup>3</sup> on fiber properties. The most important factor is the cellulose contents; cellulose is a linear polymer composed of D-glucopyranose units that are linked together with  $\beta$ -(1-4)-glucosidic bonds. The large number of OH groups attached to the pyranose rings causes its hydrophilicity. The existence of these groups also leads to numerous hydrogen bonds which form crystalline regions under the influence of van der Waals forces. In contrast, molecules with a less ordered arrangement form an amorphous region <sup>5</sup>.

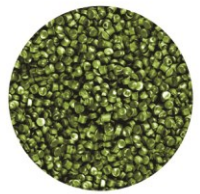


## 2. LIFE Ceplafib project – general info

LIFE CEPLAFIB project is an European consortium alliance, aiming to produce a new recycled material called CEPLAFIB for the packaging, automotive and construction industries. This will be made from deinked pulp (from recycled newspapers), recycled polypropylene and high-density polyethylene. The goal of LIFE CEPLAFIB is to demonstrate that the new material can be produced at a competitive price and that it is suitable for extended manufacturing techniques such as thermoforming and injection moulding. This three-year duration project involves partners from four EU member states (Slovenia, Finland, Poland and Spain), representing plastics and paper recyclers, manufacturers, technology suppliers and researchers.



LIFE CEPLAFIB supports EU policies on recycling and zero waste, including the Waste Framework Directive, the Landfill Directive and the Directive on Packaging and Packaging Waste. By improving product durability and recyclability it will also be in line with the goals of the Eco-design Directive. Closing the loop for the plastic and paper value chains will contribute to the implementation of the circular economy action plan.



## 2.1. Introducing recycled materials to extended areas of applications

Challenge for plastics recyclers is that their customers (plastics converters), demands large quantities of recycled plastics, manufactured to strict specifications at a price that has to be lower or at least competitive with virgin plastic. Technical requirements can vary greatly depending on the end use required by the buyer. Meanwhile, quantities available to recyclers and tonnages of recycled resins produced can be of varying quality as there is no EU-wide certification in place. The market for recovered plastics is still small in comparison with virgin plastics, and subject to the broader economic climate as well as several other factors that can be volatile in nature. Since recycled plastics aim to partly replace virgin polymers in existing applications, their market value is directly linked to virgin plastic prices, which depend heavily on volatile oil prices. The price of oil has increased significantly in the last few years, from a range of around €15-30 per barrel prior to 2004 to around €85-100 in recent years. Hence, although higher oil prices also increase the cost of collection and recycling to some extent, recycled plastics has become more attractive relative to virgin plastics. If demand from Asia (the principal importer of waste plastics from the EU) decreases, or if there is excess capacity in the virgin polymer industry, recycled plastic will only compete with virgin plastics to the extent that it can match virgin quality at the same or lower cost, or provide a level of quality that is lower but acceptable at a lower price. In many cases today, recycled plastic has a price advantage.

Consumer perception also plays a role for the market up-take of recycled plastics. The use of recycled plastics in some sectors, e.g., automotive or construction, is limited by the negative perception of the robustness of recycled material that could lead to a premium being put on virgin plastics. This effect is reduced when the recycled plastic is an intermediate product, as end users are less (or not at all) aware of its presence. However, as mentioned above some cases of negative perception are due to a lack of information, which can be overcome through market signals, while others (e.g., colour) are likely to be resolved with the next few years as technology advances.

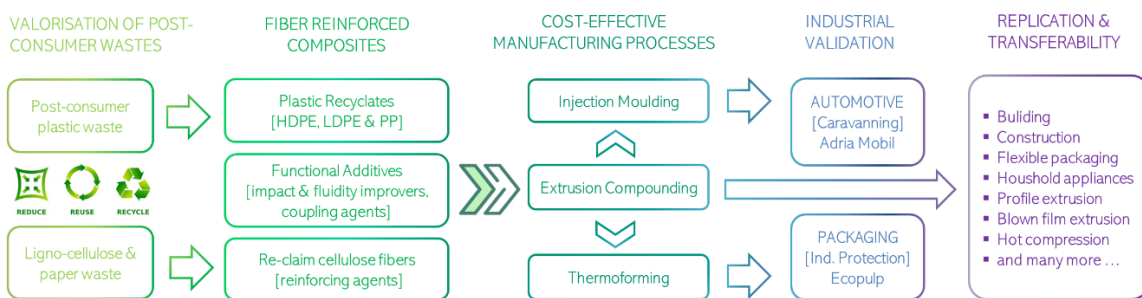


## 2.2. Evidence of novelty provided by CEPLAFIB processing technologies

*The vision of CEPLAFIB project is to create a paradigm shift in plastic recycling by establishing a novel Circular Economy approach based on the efficient use of low value mixed waste and the conversion of this material into value-added products for automotive, packaging and building-construction sector.*

The innovation potential of CEPLAFIB project arises from the novel circular economy concept of the newly established recycling value chain, by combining the two diverse waste flows into new recycled products that are sustainable and cost competitive with virgin counterparts. The value chain utilises post-consumer plastic and paper waste as a feedstock, which in medium-to-long term will significantly reduce the proportion of waste sent to landfill, contribute to the achievement of the ambitious target set by the last amendment of the European Strategy for Plastics in a Circular Economy<sup>1</sup>, where 55% of plastic packaging waste should be recycled by 2025, while the new up-cycling technologies will help to conserve the abiotic primary raw resources and energy inputs.

### CEPLAFIB circular economy approach for transformation of wastes into large-scale added value products



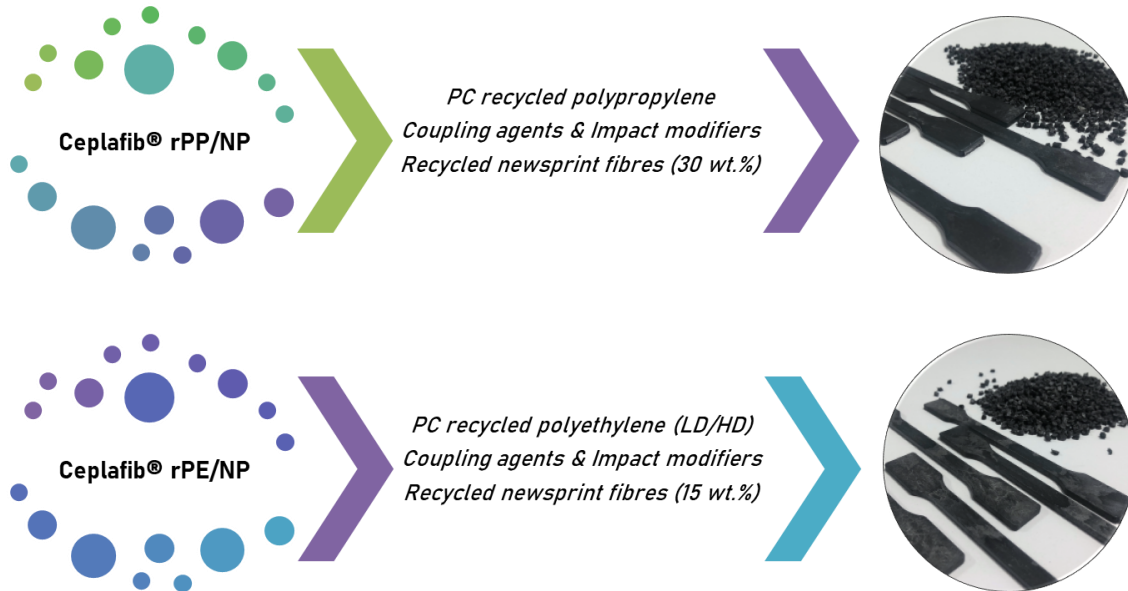
CEPLAFIB project encourage the innovation by combining the knowledge, skills and expertise of different partners in the consortium to provide solutions on how to reduce the cost-to-performance ratio of recycled plastic via an integrated approach, e.g., combining low value plastic waste with recovered fibres derived from paper waste with

<sup>1</sup> COM/2018/028: A European Strategy for Plastics in a Circular Economy



near to zero waste left-overs. The project focuses on the development of novel fibre reinforced composites based on recycled PP and HD/LD PE matrices and recovered pulp fibres from newsprint paper waste residues. There are basically two different ways and/or their combination to obtain the recovered fibres from waste residues. By mechanical approach it is possible to affect the fibre surface to increase the surface/volume ratio and the length/diameter ratio, while the innovative technology of controlled defibration and cavitron-treatments of pre-mechanically treated pulp allows fine-tuned quality of the resulted fibre material. By applying the post-chemically oxidation treatments to the fibre surface at the end of the recovering process, the retention between the fibres and binder-material (plastic) is assured and implemented in high-strength composite materials. In relation to the recycled plastic matrices, a specially developed in-house technology allows us to produce different polymer matrices, i.e., polypropylene (PP), high-density polyethylene (HDPE), low density polyethylene (LDPE), and its mixtures (PE HD/LD), all in a consistently high quality obtained 100% from post-consumer waste streams. Material properties like flowability, impact resistance or heat resistance can be now with the OMPLAST's innovative technological process tailored specifically to the requirements of the final products - with the further option of various colour ranges from the RAL spectrum. In short, for injection moulding and thermoforming processes, the output recycled resins offer a sustainable alternative to new plastics, without compromising on quality.

If those two components are merged together in appropriate proportions and by addition of special binders (i.e., coupling agents) and impact strength improvers, we can create completely new materials, adapted to the final needs of the application or product. By this we mean that through appropriate combination of composite components (recycled plastic matrices, newsprint paper fibres and special additives) we can create new composites, specifically tailored to the needs of customers, in terms of mechanical, thermal, morphological and physical properties.



Currently, post-consumer waste recycling processing infrastructure is not as advanced in the countries of the CEPLAFIB Consortium as in other European countries and the value of waste (gate fees) is still high which presents a significant business opportunity for the deployment of a first-of-a-kind CEPLAFIB process. Once proven, this technology will be available across the EU as the current overcapacity for incineration comes to the end of its lifespan.



### 3. Circulation of raw materials in the economy - circular economy

#### 3.1. EU context

The 7th Basic Requirement of the **CPR** (CPR no. 305/2011) stating that construction works must be designed, built and demolished in such a way that the use of natural resources is sustainable and ensures in particular: reuse or recycling of buildings and non-building structures, as well as their materials and parts after demolition, thus ensuring the durability of building structures; use of environmentally friendly raw and secondary materials in building structures, was a milestone towards sustainable use of natural resources in EU construction <sup>6</sup>. In December 2015, the European Commission adopted the Circular Economy Package <sup>7</sup>, containing a plan for implementing the CE model in Member States <sup>8</sup> (updated in early 2019 <sup>9</sup>). The plan outlines a series of actions to create policies and mechanisms to maximize the use of raw materials already in the economic cycle, reduce waste, and create new products that are more environmentally friendly and designed in consideration of the life-cycle perspective. The Single Market for Green Products Initiative (SMGP) was established in 2011 <sup>10</sup> with the aim of creating uniform conditions for measuring the environmental performance of products and services available on the EU market. As a result, recommendations (2013/179/EU) <sup>11</sup> for the use of common methods for measuring environmental footprint throughout the life cycle of products (PEF) <sup>12</sup> and organizations (OEF) were published in 2013 <sup>13</sup>. PEF and OEF build on existing methods and standards, and were developed through an intersectoral approach. The pilot phase lasted three years (2013-2016), while a transitional phase is currently underway prior to the eventual adoption of policies implementing PEF and OEF <sup>14</sup>. The implementation of the CE requires a systematic analysis of the progress made and the difficulties encountered, and therefore Key Indicators for monitoring the framework were developed, comprising 10 indicators describing the <sup>15,16</sup> changes occurring in the economy and based on official statistical data (among others, Eurostat, Joint Research Centre and the European Patent Office).



### 3.2. Poland

Making fundamental changes in the way a country's economy operates is a complex process. Transformation of a linear economy towards the circular model, i.e., the so-called circular economy (CE), is a challenge faced by many European countries, including Poland. Changing how a product is managed in the last phase of its existence is the element that fundamentally distinguishes an economy with a linear model from a CE. The essence of the CE concept, in terms of raw materials, is to strive to prevent waste by extending the life cycle of a product or the ability to repair it, among other things. Where waste is unavoidable, it should be suitable for reuse or recycling in accordance with the waste management hierarchy <sup>8</sup>.

As the sixth largest economy in the EU, with a GDP per capita of 71% of the EU average in 2018 <sup>17</sup>, the Polish economy has experienced by the effects of depletion of natural resources, which include growing prices and increasing dependence on foreign suppliers. This situation is particularly troublesome in the construction industry, one of the most resource- and energy-intensive sectors of the economy, which has additionally faced a serious problem of staff shortages for several years. Domestic consumption of raw materials is clearly growing, and the dynamics of this growth varies by material group. For example, from 2015 to 2018, domestic consumption of unalloyed aluminum increased by 97.7%, plastics - by 29.9%, float glass - by 28.2%, metallurgical products - by approx. 38.0%, wood-based materials - chipboard - by 25.6%, cement - by 21.7%, while paper and cardboard - by 10.0% <sup>18</sup>, while the construction industry recorded a 23.2% increase in construction and assembly production <sup>19</sup>.

The draft Polish CE roadmap, adopted in September 2019 <sup>20</sup>, is based on a model which assumes the coexistence of *biological nutrients, designed to re-enter the biosphere safely and build natural capital, and technical nutrients, which are designed to circulate at high quality without entering the biosphere* <sup>21,22</sup>. The closure of the biological and technical loops is meant to drastically limit the demand for primary raw materials while reducing the amount of generated pollution and waste. Actions included in the CE



Roadmap are mandatory at all national levels and serve to fulfill the four Polish priorities related to implementation of CE <sup>8</sup>, namely:

- a) innovation, strengthening cooperation between the industry and the scientific research sector and, as a result, implementing innovative solutions in the economy;
- b) creating a European market for recycled raw materials;
- c) ensuring high quality of recycled raw materials;
- d) development of service sector.

#### 4. Properties of the postconsumer-waste-based materials

One of the greatest challenges for plastic recycling is to obtain a recyclate characterized by properties which are at least similar to those of an equivalent material made of primary raw materials and, at the same time, maintain a similar price. Primary consumers from the plastics processing industry, building materials industry and other industries will be interested in using recycled plastics, provided they are produced to well-defined specifications which ensure uniformity and repeatability of properties. Creation of certification systems for recycled plastics to increase the confidence of industry and consumers in this group of materials may be an important instrument in this regard. Such proposal is included in the European Strategy for Plastics in a Circular Economy <sup>23</sup>.

Characteristics of recyclates should include the required properties defining basic features of the material and additional properties - related to the specific applications. A list of materials developed within the scope the Ceflafib project obtained by recycling post-consumer waste is presented in Table 1.



Table 1. List of materials developed within the scope of the Ceplafib project obtained by recycling post-consumer waste.

No.	Material name	Material symbol
1	Polyethylene regranulate	rPE (LD:HD - 50:50)
2	Polyethylene regranulate	rPE (LD:HD - 30:70)
3	Polypropylene regranulate	rPP
4	White cellulose fibres	CF
5	Cellulose made of newsprint	NP
6	Cellulose made of compressed newsprint	NP (briquettes)
7	rPP regranulate containing 30% by volume of cellulose fibres	rPP / NP
8	Composite 1 in rPP warp containing 30% vol. NP. (in form of tiles with the dimensions: 1) 14.9 x 6.3 x 0.3 cm; 2) 35 x 0.98 x 0.3 cm )	rPP / NP
9	Composite 2 in rPE (LD:HD - 50:50) warp containing 20% vol. NP. (in form of sheets with dimensions: 140 x 33 x 0.15 cm)	rPE (HD:LD 50:50) + NP
10	Composite 3 in rPE (LD:HD - 30:70) warp containing 20% vol. NP. (in form of sheets with dimensions: 140 x 33 x 0.15 cm)	rPE (HD:LD 70:30) + NP

The methods used to test plastic recyclates are given in standards **PN-EN 15344:2010** <sup>24</sup> and **PN-EN 15345:2010** <sup>25</sup>. These standards list the required properties of recyclates and the methods for their determination. However, there is no environmental requirements for this type of materials.

#### 4.1. Ageing exposure - colour change, water absorption and swelling

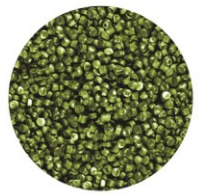
With respect to building materials, especially materials for facade cladding or external flooring, which are subjected to direct exposure to sunlight, water, temperature changes and microbiological factors throughout their entire lifetime, resistance to environmental factors is one of the key performance properties. It determines the fulfilment of the basic requirement of *Sustainable use of natural resources*, which, in accordance with Annex I to Regulation (EU) of the European Parliament and of the Council No **305/2011 (CPR)** <sup>26</sup>, constitutes one of the eight basic



requirements which must be met by construction works as a whole and by their separate parts. These regulations indicate that the civil structures should be designed and executed in a way ensuring that use of the natural resources is sustainable and ensures durability of the civil structures.

The issue of behavior of NFPC building profiles under the influence of environmental factors was considered in terms of resistance to artificial ageing through laboratory light sources <sup>27-30</sup>, hydrothermal cycles <sup>31-33</sup> and microbial action. An analysis performed by Friedrich and Luible <sup>34</sup> which summarized the results of dozens of studies conducted in recent years concerning the issue of resistance of NFPC building profiles indicated that degradation of mechanical properties is caused primarily by artificial ageing, followed by microorganisms, with hydrothermal cycles having the least impact.

Artificial ageing in principle involves subjecting the product to intense exposure to laboratory light sources to simulate ageing processes in an accelerated manner that reflects the natural weathering processes. Results of ageing tests of NFPC products indicate that the most unfavorable sequence of exposure is alternating exposure to light and water. Then the degradation of NFPCS is quicker and more intensive than in case of exposure to light alone <sup>28</sup>. This is because rinsing leaches particles previously damaged by UV radiation and exposes the particles lying underneath. Irradiation and rinsing cycles are more destructive for profiles whose surface had been previously machined compared to profiles whose surface had not been altered after extrusion <sup>27</sup>. Composites with a higher proportion of lignocellulosic particles on their surface, which are exposed through planning, show a higher degradation of flexural strength and flexural modulus <sup>29</sup>. It was also found that NFPCs degrade faster than the polymer used as a matrix. Pure polymer in initial stage of ageing may still undergo crosslinking, while in composite this ability is physically limited by a presence of filler particles <sup>28</sup>. Of course, exposure time is significant. The longer it takes, the more degradation it causes <sup>27,35</sup>.



The rPP/NP, rPE (LD:HD - 30:70) and rPE (LD:HD - 50:50) composites were subjected to accelerated ageing consisting of exposure to laboratory light sources - fluorescent lamps type 1A (UVA-340) according to **EN 16474-3**<sup>36</sup>- alternating with humidification. The exposures were performed according to **EN ISO 4892-3** cycle 4<sup>37</sup>. Samples were subjected to cycles consisting of irradiation with light emitted by UV lamps, at an irradiance of 0.83 W/m<sup>2</sup>, combined with high temperature, alternated with humidification via spraying with deionized water with pH of 5.0±7.5 and an electrical conductivity of less than 2 µS/cm measured at 25°C. Artificial ageing was performed continuously for 42 days what resulted in implementation of 168 cycles.

The results of the color change test, determined according to **ISO 7724-2**<sup>38</sup> and **ISO 7724-3**<sup>39</sup> are summarized in Figure 1. Error bars illustrate the standard deviation. By analysis of the  $\Delta E_{ab}$  values, it can be concluded that rPE (LD:HD - 30:70) and rPP/NP composites showed high color stability during artificial ageing. It is assumed that a change in  $\Delta E_{ab}$  of less than 5 units is not detectable to the naked eye. At the same time, it should be noted that increasing the duration of artificial ageing can lead to a deepening of the color change<sup>27</sup>. Colour change for the rPE (LD:HD - 50:50) composite of approx. 7 units can be considered acceptable for most applications in the construction sector; it should also be noted that for facade elements, colour stability of up to 5 units can be expected. It should be added that a number of polymer composites reinforced with lignocellulosic fibers distinguish with low colour stability. Some NFPCs show colour change under the action of light on the level 30-40 units<sup>40</sup>, what obviously limits their range of application.

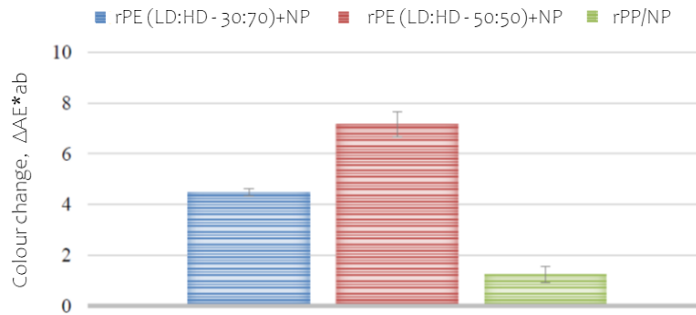


Figure 1 Colour change test results.

In a number of works devoted to plant fibre reinforced polymer composites, research concerning resistance to environmental factors is at the forefront <sup>27,28,33,35,41-43</sup>. The hydrophilic nature of plant fibres means that they easily swell in an aqueous environment, causing cracks to form in the hydrophobic polymer matrix <sup>28</sup>. It also worsens the interaction between the lignocellulosic particles and the polymer, reducing the stress transfer capability between the fibres and the matrix <sup>27</sup>. As a consequence, the mechanical parameters of the composite deteriorates. Solar radiation, especially the UV band, leads to cracking, peeling or color change of the surface of the profile <sup>35</sup>.

The results of water absorption and swelling tests based on soaking of the composites in water for 28 days are shown in Figure 2 and Figure 3, respectively. The tests were carried out according to the guidelines of EN 15534-1 <sup>44</sup>.

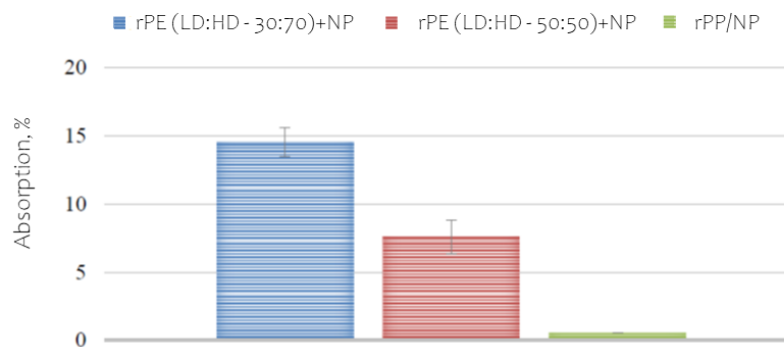


Figure 2 Water absorption test results.

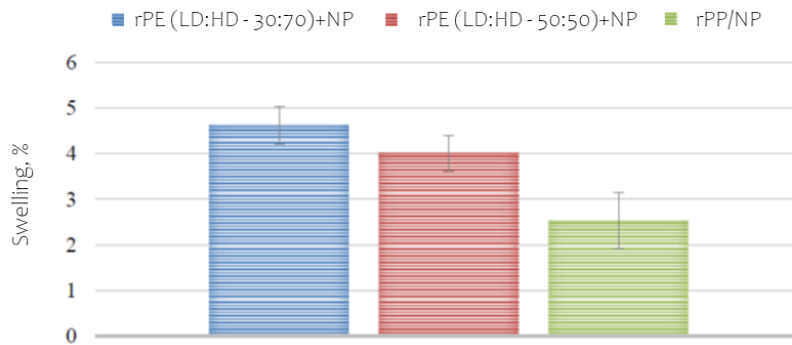


Figure 3 Swelling test results.

Error bars illustrate the standard deviation. Far the highest susceptibility to action of water has been shown by rPE (LD:HD - 30:70), for which the 15% absorption and 4.5% swelling has been recorded, while for rPE (LD:HD - 50:50) composite the 7% and 4%, and for rPP/NP only 0.5% and 2.5% has been recorded, respectively. The results obtained for PE HD/LD 70/30 are noticeably higher than those reported for NFPCs with PE matrix <sup>45,46</sup>. The high susceptibility of PE HD/LD 70/30 composite to action of water may be a factor for limiting its use in the construction industry. Fibers swelling leads to the formation of cracks in the polymer matrix <sup>28</sup>, which deteriorates the cooperation between the lignocellulosic fibers and the polymer, reducing the stress transfer ability between the fibers and the matrix <sup>29</sup>. As a consequence, a significant deterioration in the mechanical performance of the composite should be expected over time. Therefore, rPE (LD:HD - 30:70) composite due to susceptibility to action of water should not be used for production of components subject to full exposure to the environmental factors. Comparing the results of water absorption and swelling tests for the rPE (LD:HD - 50:50) and the rPP/NP composites with the requirements specified in EN 15534-4 <sup>47</sup> for NFPC products for external flooring (absorption  $\leq 7\%$ , swelling  $\leq 4\%$ ) or in EN 15534-5 <sup>48</sup> with respect to NFPC facade profiles (absorption  $\leq 7\%$ , swelling  $\leq 10\%$ ), it can be concluded that the water susceptibility of these composites is acceptable in terms of solutions for outdoor applications in the construction sector.



## 4.2. Mechanical properties

Natural fibers with a high percentage of cellulose, especially crystalline cellulose, are characterised by the highest mechanical properties <sup>49</sup>. The other major component of fiber is hemicellulose, which is a branched polymer with low strength compared to crystalline linear cellulose. Hemicellulose, like lignin, is highly hydrophilic <sup>5</sup>. High proportion of hemicellulose in the fibers results in lower strength and increases water absorption <sup>49</sup>. Lignin, on the other hand, increases the rigidity of the fiber structure by combining cellulose with hemicellulose. The properties of the fibers are also determined by their structure. Plant fibers have a multilayer structure. Each layer is formed by bundles of parallel cellulose microfibrils fused by lignin, hemicellulose, pectin and other amorphous components. Microfibers are arranged spirally with respect to the fiber axis, at different angles<sup>5</sup>. The most common matrices in NFPCs include polypropylene (PP), high density polyethylene (PEHD), polyvinyl chloride (PVC), and less commonly, polystyrene (PS). Their basic properties are listed in Table 2. The choice of matrix is dictated by the intended use of the composite. Polyvinyl chloride has high strength, but also has relatively low impact strength. While polyethylene has lower strength, it has significantly higher ductility. An intermediate solution is polypropylene. Aiming at biodegradable NFPCs, matrices of biodegradable polymers such as polyglycolide (PGA) or polyhydroxyalkanoates (PHA) are also introduced <sup>49</sup>. Thermosetting polymers include epoxy, polyester (UP) and polyurethane (PU) matrices, as well as biodegradable polycaprolactone (PCL). Profiles used in the construction industry usually have a PVC or PEHD matrix.

Table 2. Properties of selected polymers used as matrices for NFPCs <sup>49</sup>.

Polymer	Tensile strength, MPa	Elastic modulus in tensing, GPa	Flexural strength, MPa	Elastic modulus in flexing, MPa
PE(HD)	15-78	0.2	17	0.055-1.5
PP	26-41	1.3	40	1.0-1.8
PVC	41-52	2.5-4.1	69-114	2.8
PS	25-69	2.8	70	4.0-5.0



Ensuring an effective interaction between the lignocellulosic fibers and the polymer matrix is one of the fundamental challenges for the manufacture process of NFPCs composites. Insufficient adhesion at the interfacial limit leads to a decrease in both mechanical properties and their water resistance<sup>50</sup>. The source of the problem is the hydrophilic nature of the fibers. In order to eliminate it, various fiber surface modification methods have been developed, aimed at both improving wettability and reducing water absorption. The most popular are chemical methods, which involve the use of substances whose molecules react with hydroxyl groups of cellulose and introduce new groups that combine with functional groups of the polymer matrix<sup>50</sup>. These include immersion in alkalis (using NaOH), application of silanes (SiH<sub>4</sub>), acetylation (using acetic acid CH<sub>3</sub>COOH), benzylation (using benzoin chloride containing C<sub>6</sub>H<sub>5</sub>C=O), acrylation (using CH<sub>2</sub>=CHCOOH) and a number of others<sup>50</sup>. Physical methods include plasma, corona discharge, steam explosion, high energy radiation, autoclaving<sup>51</sup>. The properties of NFPCs are also affected by the number and distribution of fibers<sup>3</sup>. Proper fiber dispersion in the matrix facilitates good interfacial adhesion, reducing voids, ensuring that the fibers are fully surrounded by the matrix<sup>49</sup>.

The results of impact strength test of rPP/NP composite, tested by Charpy method according to **EN ISO 179-1** are summarised on Figure 4<sup>52</sup>. The material was tested in its initial state (laboratory conditions), after artificial ageing (UV) according to **EN ISO 4892-3** cycle 4<sup>53</sup> and after hydrothermal cycles (HT) according to **EN 15534-1**<sup>44</sup>. Error bars illustrate the standard deviation. There was a 17% decrease in impact strength after artificial aging, and a 5% decrease after hydrothermal cycles. The above indicates that, particularly under the influence of UV light, the resistance of the rPP/NP composite to dynamic loads decreases, but remains above 8 kJ/m<sup>2</sup>, which can be considered a satisfactory value for many applications in the construction sector<sup>54</sup>.

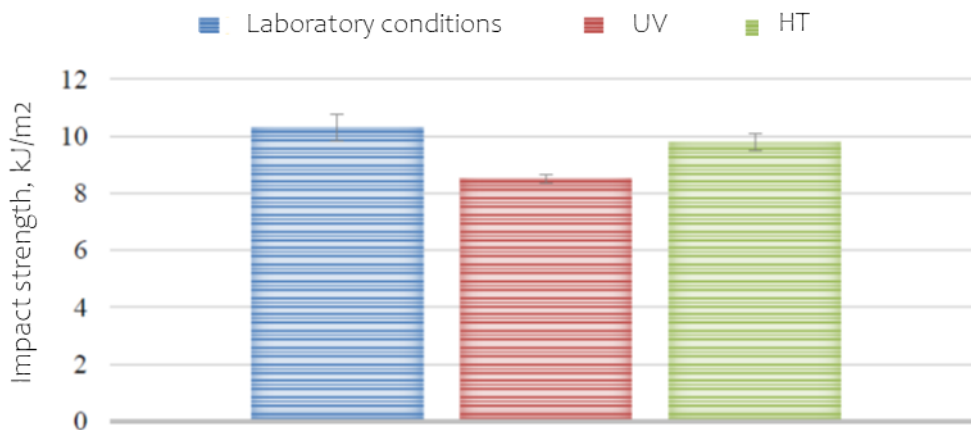


Figure 4 Charpy impact test results of rPP/NP composite <sup>52</sup>.

The results of mechanical testing of rPE (LD:HD - 50:50)+NP and rPE (LD:HD - 30:70)+NP composites under laboratory conditions, after artificial aging (UV) according to EN ISO 4892-3 cycle 4 <sup>53</sup> and after hydrothermal cycles (HT) according to EN 15534-1 <sup>44</sup>, are presented on Figure 5 and Figure 6.

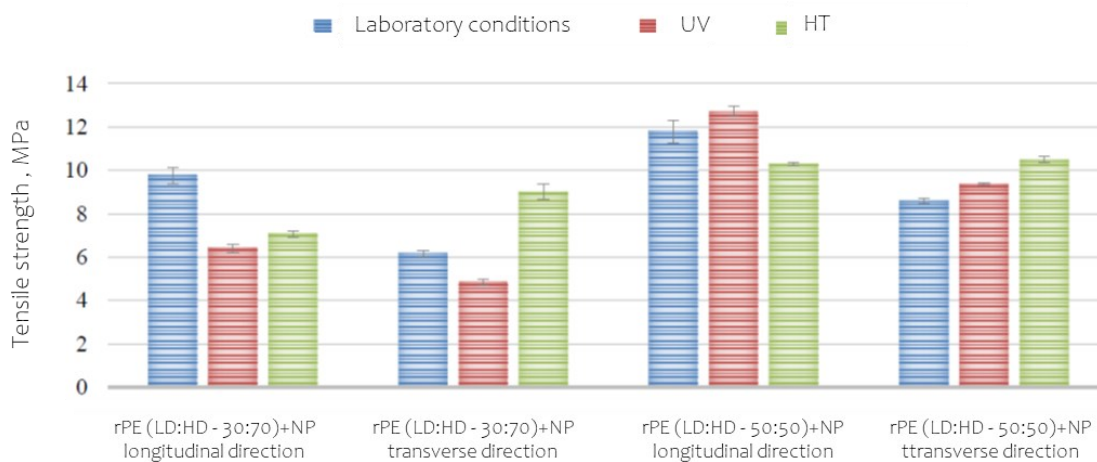


Figure 5 Tensile strength test results of rPE (HD:LD 70:30)+NP and rPE (HD:LD 50:50)+NP composites according to EN ISO 527-2 <sup>55</sup>.

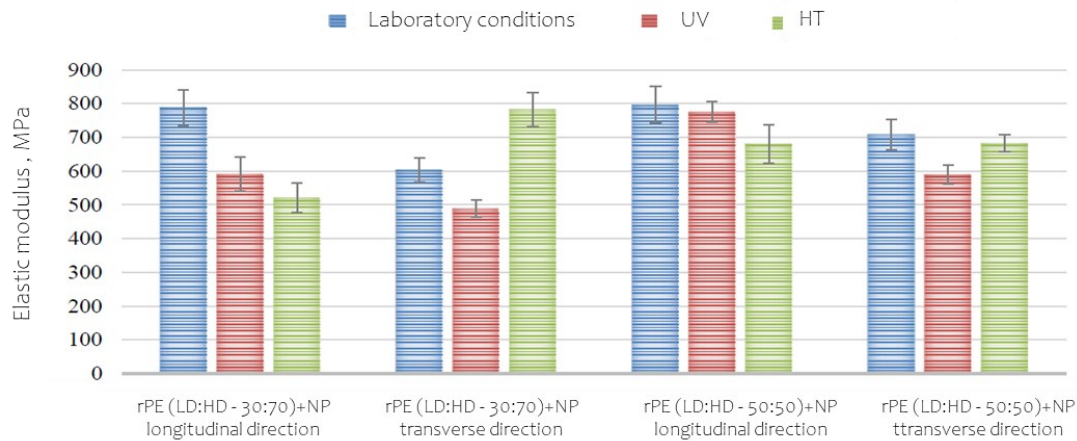


Figure 6 Elastic modulus in tensing test results of rPE (HD:LD 70:30)+NP and rPE (HD:LD 50:50)+NP composites. according to EN ISO 527-2<sup>55</sup>.

The obtained values of tensile strength and elastic modulus in tensing (test performed according to EN ISO 527-2<sup>55</sup>) of both rPE (HD:LD 70:30)+NP and rPE (HD:LD 50:50)+NP composites indicate the anisotropy of the materials. In the longitudinal direction (parallel to the length of the sheet) the values of tensile strength in the range of 10-12 MPa were obtained in the initial state, in the transverse direction - 6-8 MPa, and the elastic modulus in tensing in the longitudinal direction - 800 MPa, and in the transverse direction - 600-800 MPa. The results of tensile strength correspond with the results of other NFPCs with PE matrix<sup>56</sup>, although it should be noted that they are low compared to other solutions. A modulus of elasticity of less than 1000 MPa should be considered a very low value<sup>57</sup>, which may significantly limit the range of application in the construction sector. The set exposures, both artificial aging and hydrothermal cycles, resulted in a 20-40% reduction in tensile properties for most of the test series considered, indicating a moderate resistance of the solutions considered to the set exposures. The reported increase in the values of some parameters in the transverse direction tests is probably due to the heterogeneity of the product.



### 4.3. Thermal properties

In light of the push for zero-energy building, the thermal properties of materials, especially those used in construction, is now a widely debated issue. The parameter describing the thermal properties of a material is the thermal conductivity coefficient  $\lambda$  (lambda). The coefficient is a physical property that determines the amount of heat energy flowing through a material as a result of a temperature difference. Materials used for thermal insulation purposes in the construction industry have to meet high requirements in terms of heat transfer coefficient (the lower the  $\lambda$  value, the better the thermal insulation properties), while in the context of other performance characteristics, mechanical properties and resistance to changing temperature and humidity conditions are also important.

The values of thermal conductivity coefficient are calculated from Fourier's equation, based on the sample thickness, temperature values and heat flux at both edges of the sample according to the formula:

$$q = -\lambda \frac{\Delta T}{\Delta x}$$

where  $q$  is the heat flux density [ $\text{W}/\text{m}^2$ ];  $\lambda$  the thermal conductivity of the material [ $\text{W}/(\text{m}\cdot\text{K})$ ], and  $\Delta T/\Delta x$  the temperature gradient [ $\text{K}/\text{m}$ ].

A FOX 50 plate apparatus with a shielded heating plate (direct measurement method<sup>58</sup>) was used to measure the thermal conductivity coefficient  $\lambda$  of the materials developed in the Ceplafib project, according to EN 12664:2002<sup>59</sup>.

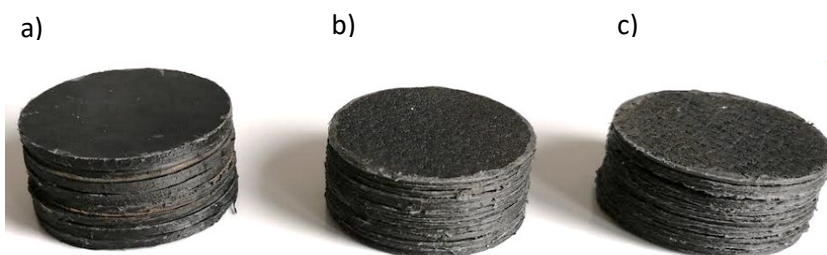


Figure 7 Test samples: a) rPP/NP b) rPE (LD:HD - 30:70) c) PE (LD:HD - 50:50).



Measurements were made at average sample temperatures of:  $-10^{\circ}\text{C}$ ,  $5^{\circ}\text{C}$ ,  $10^{\circ}\text{C}$ , and  $15^{\circ}\text{C}$ , a temperature difference across the sample thickness of 10 K (at the obtained average spacing temperatures of  $5^{\circ}\text{C}$  and  $10^{\circ}\text{C}$ ) and 20K (at the obtained average spacing temperatures of  $-10^{\circ}\text{C}$  and  $15^{\circ}\text{C}$ ), and vertical upward heat movement. The dimensions of the test samples were disc diameter approx. 0.049 m, and the thickness of the test samples to approx. 0.024 m. The test samples are shown at **Napaka! Vira sklicevanja ni bilo mogoče najti.**

Prior to testing, samples were conditioned for 24 hours at  $(23 \pm 5)^{\circ}\text{C}$  temperature and 50% RH relative humidity.

The relative weight change of the samples during conditioning as well as during testing did not exceed 0.1%.

The following composite materials were tested:

- rPP/NP with a density of approx.  $970 \text{ kg/m}^3$  and a nominal material thickness of 0.0030 m,
- rPE (LD:HD - 30:70) with a density of approx.  $760 \text{ kg/m}^3$  and a nominal material thickness of 0.00135 m,
- rPE (LD:HD - 50:50) with a density of approx.  $865 \text{ kg/m}^3$  and a nominal material thickness of 0.00155 m.

Thermal conductivity test results for composite materials are summarised in Figure 8.

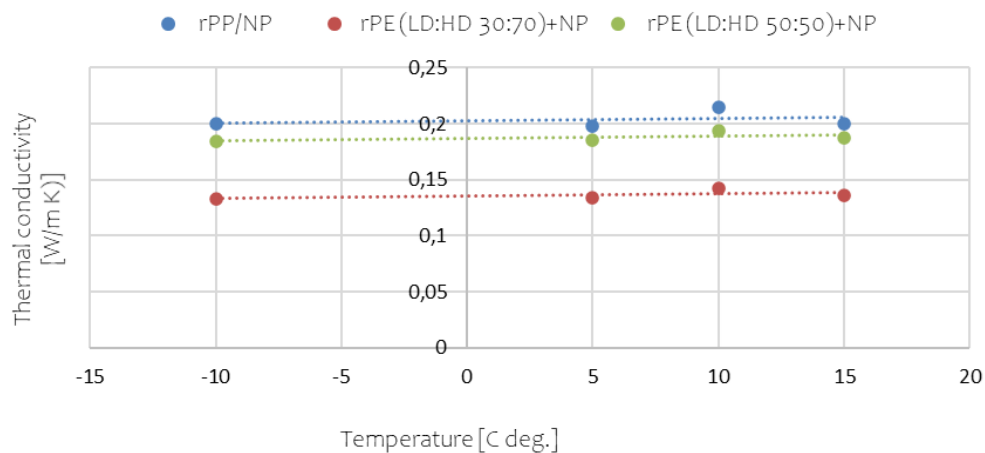




Figure 8 Thermal conductivity  $\lambda$  test results of rPP/NP, rPE (LD:HD - 30:70) and rPE (LD:HD - 50:50) composites.

The thermal conductivity coefficient  $\lambda$  of materials used in construction is usually determined for an average sample temperature of 10°C. For most materials used in construction, the value of this coefficient depends on the density of the material and usually increases with increasing density. The results obtained for the thermal conductivity coefficient of the composites are similar to the values of thermal conductivity coefficients of analogous materials, included in the composites, and manufactured from primary raw materials, according to the data contained in EN ISO 10456:2010<sup>60</sup> – Table 3.

Table 3. Thermal conductivity coefficients of selected materials<sup>60</sup>

Material	Density [kg/m <sup>3</sup> ]	Thermal conductivity coefficient [W/(m-K)].
Cellulose (short fibre)	30-70	0.06
Polyethylene (LDPE)	920	0.33
Polyethylene (HDPE)	980	0.50
Polypropylene	910	0.22

Analysing the results obtained, it can be seen that the addition of cellulose caused a decrease in the value of the thermal conductivity coefficient of the composite in comparison with pure PE, thus had an effect on improving the insulation properties. In the case of rPP/NP, which has a much higher density compared to PP, only a slight increase in thermal conductivity values was observed, which confirms the prediction that the addition of cellulose improves the thermal insulation of the material.

#### 4.4. Release of ions and heavy metals

To evaluate the environmental impact of the rPP/NP composite as an exterior façade panel, ion and heavy metal release tests were conducted. The tests performed were based on the methods contained in CEN/TS 16637-2:2014<sup>61</sup>. The tests investigated the release of hazardous substances from building products into surface water,



groundwater and soil. The purpose of the test was to determine the characteristics of the leaching process and to evaluate the release of hazardous substances during the use of the product.

In the case of uniform materials, i.e. rPP/NP composite, the product sample was placed in a leaching vessel with the exposure surface completely covered by the leaching liquid. The leaching liquid was fed into the vessel, in a specified volume, according to the surface ratio, which is calculated from the formula described in the method. The leaching liquid was replaced according to the schedule contained in Table 4.

Table 4. Leaching liquid replacement schedule according to <sup>61</sup>

Stage	Stage duration	Time since start of the test
1	6 h	6 h
2	18 h	1 day (24 h)
3	1 day and 6 hours (30 h)	2 days and 6 hours (54 h)
4	1 day and 18 hours (42 h)	4 days (96 h)
5	5 days (120 h)	9 days (216 h)
6	7 days (168 h)	16 days (384 h)
7	20 days (480 h)	36 days (864 h)
8	28 days (672 h)	64 days (1536 h)

Physical properties were measured in the collected eluates:

- pH according to **PN-EN ISO 10523:2012** <sup>62</sup>
- electrical conductivity according to **EN 27888:1999** <sup>63</sup>  
and the inorganic components were determined, i.e:
- total organic carbon (TOC) according to **PN-EN 1484:1999** standard <sup>64</sup>
- anions (fluorides, chlorides, bromides and sulfates) according to **PN-EN ISO 10304-1:2009** <sup>65</sup>
- heavy metals according to **PN-EN ISO 11885:2009** <sup>66</sup>
- mercury according to own procedure

The leaching results of hazardous substances were compared with the permissible values adopted for industrial wastewater discharged to water or to the



ground according to the *Regulation of the Minister of Maritime Affairs and Inland Navigation of 12 July 2019* <sup>67</sup>. A summary can be found in

Table 5.

Table 5. Comparison of test results with their permissible parameter values according to <sup>67</sup>.

Indicator name	Unit	Maximum allowable value <sup>67</sup>	The average value obtained for rPP/NP composite
Temperature	°C	35	22.4
pH	-	6,5-9	6.7
TOC	mg C / l	30	0.8
F <sup>-</sup>	mg F <sup>-</sup> / l	25	0.1
Cl <sup>-</sup>	mg Cl <sup>-</sup> / l	1000	0.1
SO <sub>4</sub> <sup>2-</sup>	mg SO <sub>4</sub> <sup>2-</sup> / l	500	0.1
Σ Cl <sup>-</sup> + SO <sub>4</sub> <sup>2-</sup>	mg Cl <sup>-</sup> + SO <sub>4</sub> <sup>2-</sup> / l	1500	0.2
Hg	mg Hg / l	0.03	4·10 <sup>-5</sup>
Cd	mg Cd / l	0.2	8·10 <sup>-5</sup>
As	mg As / l	0.1	1·10 <sup>-3</sup>
Zn	mg Zn / l	2	1,34·10 <sup>-2</sup>
Total Cr	mg Cr / l	0.5	1·10 <sup>-4</sup>
Cu	mg Cu / l	0.5	8,7·10 <sup>-4</sup>
Ni	mg Ni / l	0.5	4,9 ·10 <sup>-4</sup>
Pb	mg Pb / l	0.5	1,7·10 <sup>-3</sup>

The tested composite had very low release concentrations, well below the limits adopted in the comparison. Based on the test results, the mechanisms of metal release from the composite over time, i.e., prediction of the effects of rPP/NP composite materials on the external environment in terms of metal release: cadmium, copper, zinc and lead, were determined. The following results were obtained for the release of the other substances labeled hazardous:

- no release of mercury, arsenic, chromium, nickel from the composite - concentrations below quantification;
- for chloride, bromide, fluoride and sulfate, low concentrations near the limit of quantification were found in some eluates.



#### 4.5. Impact on indoor air quality

Because of the intended use of the screens in rooms designated for human occupancy, a feature that reflects their environmental impact and exposure to humans is the release of hazardous substances into the air. Volatile organic compound (VOC) emissions from building products are a cause of indoor air pollution. The presence of VOCs can cause odors, irritation of the mucous membranes of the eyes, nose, and throat, neurological disorders, and adverse effects on residents.

VOC emission tests were conducted for acoustic barrier materials rPE (LD:HD - 50:50) and rPE (LD:HD - 30:70) composites with the intention of indoor applications.

Tests for the release of dangerous substances from were performed in accordance with EN 16516:2017-11<sup>68</sup>. The tests were related to the emission of volatile organic compounds and volatile aldehydes from composites into indoor air. The test consisted of placing the product in an emission chamber for 28 days under the following conditions:

- vented chamber made of stainless steel
- temperature:  $(23 \pm 1)^{\circ}\text{C}$
- relative humidity  $(50 \pm 5)\%$
- air change rate  $0,5 \text{ h}^{-1}$
- saturation of the chamber with the product:  $1\text{m}^2/\text{m}^3$

During the test, air samples were taken from the chamber twice: after 3 days and after 28 days from the start of the test. For the VOC test, approx. 5 liters of air, while for volatile aldehyde tests the volume of air taken was 60 liters. Air samples were analyzed by chromatographic analysis:

- volatile organic compounds in the range  $\text{C}_6\text{-C}_{16}$
- volatile aldehydes in the range  $\text{C}_1\text{-C}_4$

The obtained emission results can be related to national regulations on permissible concentrations of agents harmful to health in rooms intended for human



occupancy found in the *Ordinance of the Minister of Health and Social Welfare of 12.03.1996.* <sup>69</sup>.

The ordinance distinguishes two types of rooms:

- category A - residential, intended for permanent residence of the sick persons in the health care facilities and intended for permanent residence of children and young people in educational buildings, as well as rooms intended for storage of food products,
- category B – intended for occupancy by human in the public utility buildings other than included in the A category and auxiliary rooms in the flats.

Annex 1 to <sup>69</sup> determines allowable concentration for some of the identified chemicals. They have been compared with the values obtained from tests of composite materials in

Table 6. No allowable concentrations have been determined for the other compounds listed. In summary, the composites tested did not exceed the allowable concentrations acc. to <sup>69</sup> after 28 days of testing.

*Table 6. Allowable concentrations of chemical substances harmful to health in the air of A/B category rooms with the average concentrations of substances emitted from the tested composites.*

Identified chemical compound	Average concentrations of substances in chamber air after 28 days [ $\mu\text{g}/\text{m}^3$ ]		Allowable concentration in $\mu\text{g}/\text{m}^3$ in A/B category rooms <sup>69</sup>
	PE HD:LD 50:50 + NP	PE HD:LD 70:30 + NP	
1-Butanol	7	-	300/300
Formaldehyde	< 1	< 1	50/100

The tested composites meet the requirements of Polish regulations on the release of dangerous substances, in accordance with <sup>69</sup> and may be used in rooms of categories A and B.



In addition, the test results can be cross-referenced to the requirements for harmful substances emitted by building products according to AgBB Procedure - *Evaluation procedure for VOC emissions from building products; August 2018 Part 3: LCI values*<sup>70</sup>.

A basis for these regulations is the EU directive on the construction products, which requires that they do not pose any risk to the building dwellers. The German Committee for Health-related Evaluation of Building Products (AgBB) has given its interpretation of the observance of this clause of the mentioned directive. The approach represented by the AgBB describes minimum requirements for VOC emissions. Low emission products can also be additionally labelled with voluntary marks such as Blue Angel, GUT, EMICODE, etc. German authorities are working on introduction of this assessment programme to the regulations related to construction products in whole Europe.

Test results related to European requirements found in the EU-LCI list, which constitutes an annex to the AgBB Procedure<sup>70</sup>, did not indicate exceedance of permissible values (Table 7).

*Table 7. Test results after 28 days and permissible concentrations related to European requirements found in the EU-LCI list, which constitutes an annex to the AgBB Procedure<sup>70</sup>.*

Name of the substance	[CAS]	Allowed concentration [µg/m <sup>3</sup> ] <sup>70</sup>	Concentration after 28 days [µg/m <sup>3</sup> ]	
			rPE (HD:LD 50:50) + NP	rPE (HD:LD 70:30) + NP
Hexane	[110-54-3]	4300	< 1	< 1
Octane	[111-65-9]	14000	-	2
2,2,4-Trimethylhexane	[16747-26-5]	14000	-	< 1
2,6,10-Trimethyldodecane	[3891-98-3]	6000	-	< 1



2,2-Dimethyldecane	[17302-37-3]	6000	-	< 1
3,3,5-Trimethylheptane	[7154-80-5]	14000	-	< 1
Dodecane	[112-40-3]	6000	-	< 1
Tetradecane	[629-59-4]	6000	-	< 1
1-Butanol	[71-36-3]	3000	7	-
Nonanal	[124-19-6]	900	< 1	< 1
alpha-Pinene	[80-56-8]	2500	-	3
3-Carene	[13466-78-9]	1500	-	< 1
1-(2-butoxy-1-methylethoxy)propan-2-ol	[29911-28-2]	250	-	< 1
TVOC		1000	23	3
Formaldehyde	[50-00-0]	100	< 1	< 1
Acetaldehyde	[75-07-0]	1200	< 1	< 1
Propionaldehyde	[123-38-6]	650	< 1	< 1
Butyraldehyde	[123-72-8]	650	< 1	< 1

## 5. Possible application of the composites in construction sector

### 5.1. Facade panels

The use of the recycled rPP/NP polymer composite as an outdoor facade panel is assessed in terms of mechanical properties and weather resistance:

- flexural strength and modulus of elasticity according to **EN ISO 178 :2019-06** <sup>71</sup>, after laboratory seasoning and hydro-thermal cycling according to **EN 15534-1+A1:2017-12** <sup>44</sup>
- Charpy impact strength according to **EN ISO 179-1:2010**, <sup>72</sup>after laboratory seasoning and hydro-thermal cycling according to **EN 15534-1+A1:2017-12** <sup>44</sup>



- dimensional stability (including swelling in the thickness direction) and water absorption according to EN 15534-1+A1:2017-12 (after <sup>44</sup>hydro-thermal cycles)
- ageing resistance after 300 h of exposure according to EN ISO 4892-2:2013-06 <sup>37</sup>expressed by:
  - color changes according to ISO 7724-2:2003 <sup>38</sup>, ISO 7724-3:2003 <sup>39</sup>
  - changes in Charpy impact strength according to EN ISO 179-1:2010 <sup>72</sup>
  - changes in flexural strength and elasticity modulus according to EN ISO 178 : 2019-06 <sup>71</sup>

## 5.2. Acoustic barriers

The suitability of a product for use as a sound-absorbing product is determined by its reverberant sound absorption coefficient  $\alpha_s$ , measured in accordance with the PN-EN ISO 354 standard <sup>73</sup>, and by its practical absorption coefficient  $\alpha_p$  and its weighted sound absorption coefficient  $\alpha_w$ , determined for a product in accordance with the PN-EN ISO 11654 standard <sup>74</sup> on the basis of measurement of the reverberant sound absorption coefficient – Figure 9.



Figure 9 Reverberant sound chamber at the Building Research Institute (Instytut Techniki Budowlanej, ITB), used to measure the reverberant sound absorption coefficient  $\alpha_s$  in accordance with the PN-EN ISO 354 standard.



On the basis of the determined sound absorption coefficient, the product is classified into one of the absorption classes, marked A to E. The product qualifies as a sound-absorbing product if its absorption coefficient is greater than or equal to 0.15. Products with lower coefficients do not have a sound-absorbing function, but can be used e.g. as decorative products. Composites in PE warp, prepared within the scope of the Ceplafib project, have been tested to check whether it could be used as a cladding of acoustic barriers, intended for use inside the buildings. Diagrams of the products with photographic documentation of manufactured demonstrators are shown on Figure 10.

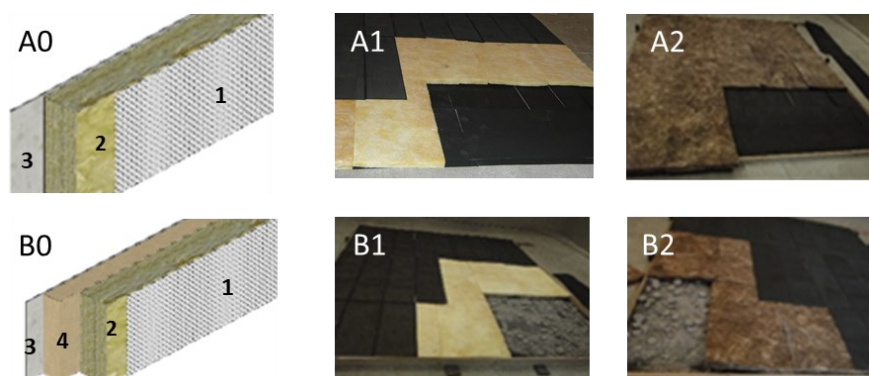


Figure 10 Diagram of acoustic barrier (1 - perforated rPE sheet (HD:LD 70:30) + NP; 2 - mineral wool type X / type Y; 3 - rPE sheet (HD:LD 50:50) + NP.; 4 - NP (briquettes)).

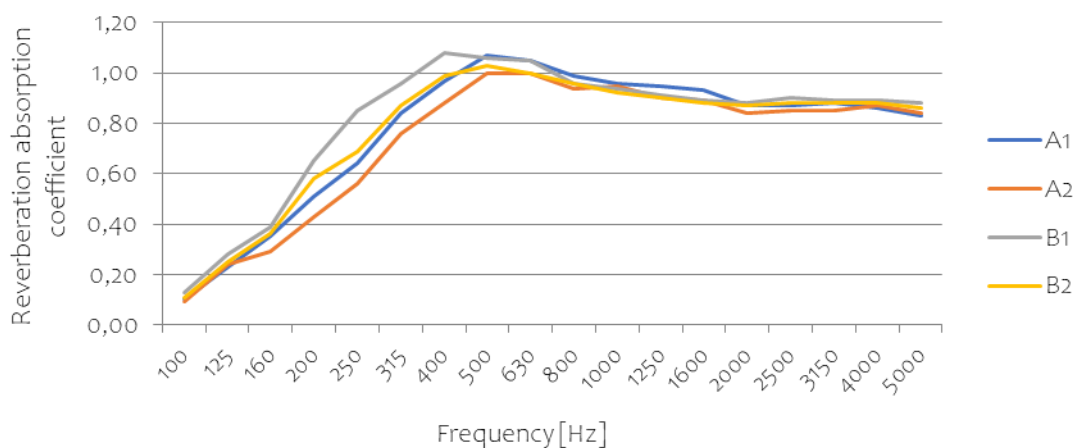




Figure 11 Reverberation absorption coefficient of A1, A2, B1 and B2 acoustic barriers (designation according to Figure 10).

Test results, shown in Figure 11, indicate that all barriers are characterised by a similar sound absorption in terms of reverberant sound absorption coefficient  $\alpha_s$  and weighted sound absorption coefficient  $\alpha_w$  as well as acoustic class (classes A and B). This is due to the use of similar surface layers: mineral wool gr. 5 cm and perforated polymer sheets. The results obtained can be considered as typical for this type of construction products. The tested demonstration acoustic barriers qualify as sound-absorbing products and, in terms of acoustics, can be used for acoustic adaptation of rooms in industrial facilities and general use buildings. The sound-absorbing properties of all the tested claddings are almost analogous. The scope of their application should be determined individually, depending on the type and function of the adapted rooms and the acoustic requirements stemming from applicable standards and regulations.

There are no normative requirements for acoustic barriers used indoors, so to assess their performance it is recommended to use the guidelines found in standards EN 1793-1:2017-05<sup>75</sup> and EN 1794-1:2018-04<sup>76</sup> concerning road traffic noise reducing devices. These standards contain the acoustic and non-acoustic requirements for this type of products.

### 5.3. Air diffusers

According to provisions of the **Technical Conditions Regulation**<sup>77</sup>, the supply of air from outside the building to rooms intended for permanent or temporary human occupancy in the amount necessary for ventilation purposes is ensured by air supply devices located in window and door joinery or in other parts of external partitions. These are typically devices for supplying outdoor air to rooms, used in all ventilation systems (passive, mechanical and hybrid). Every air supply device that is placed on the market must meet the flow characteristics that are specified in the documents of each country. In Poland, the required nominal and minimum flow rates are specified in the Polish



Standard **PN-B-03430:1983/Az3:2000**<sup>78</sup>. According to the applicable regulations, art. 9 para. 1 item 1 of the **Construction Products Act**<sup>6</sup>, every air supply device placed on the market is covered by a National Technical Assessment (NTA), previously Technical Approval (TA), which constitutes a reference document for assessment of conformity and placement of the product on the domestic market with the "B" construction mark. The fact that there is no Polish Standard for air supply devices that would take into account the technical and performance requirements for this class of construction products made it necessary to develop **Recommendations for Granting Technical Approvals (ZUAT)**<sup>79</sup>, which present the rules for assessment of and testing methods for air supply devices, with a particular emphasis on their performance depending on pressure difference<sup>80</sup>. Air supply devices are made of 2 main components: flow regulator installed inside the room and air intake installed on external side of the window, balcony doors or partition. Most air supply devices are equipped with meshes against insects, sometimes with filters that are designed to stop contaminants in the air flowing into the room<sup>81</sup>. The most common material used in manufacturing of air supply devices is poly(acrylonitrile-co-butadiene-co-styrene) (ABS), which is used to make bodies of the air intake and the regulator; aluminium elements and styrene copolymer shields are also manufactured. Additional components such as caps are made of polyamide, gaskets are made of EPDM, and the safety mesh is made of metal or PVC. There are no hygienic requirements for the use of air supply devices, however, manufacturers sometimes perform hygienic approvals for their products. The durability of both metal and aluminium components will depend on the type of metal used, the environment in which it will be installed as well as the corrosion protection. For example application of paint coatings allows to give any colours to the products which in turn creates great possibilities for their use. The rPP/NP, rPE (LD:HD - 30:70) and rPE (LD:HD - 50:50) composites produced within the scope of the Ceplafib project can be successfully used as material for air supply devices and their components.



## 5.4. Air grating

The foundation of healthy climate in residential rooms is a properly designed and built ventilation system, which ensures sufficient air exchange, i.e. the amount and quality of air needed for hygiene and sanitary reasons. As a general rule, the amount of air supplied to a room should be equal to the amount of air removed from that room. Nowadays, with buildings having tight external walls as well as window and door joinery, air is supplied to rooms primarily through intake vents, and removed from rooms through ventilation ducts, which are covered by air grating from the room side. Air grating is meant to ensure uninterrupted air flow, which in turn ensures proper functioning of the ventilation system. Depending on the intended use of air grating, for assessment of its performance in Poland it is recommended to use the guidelines developed by the Building Research Institute (Instytut Techniki Budowlanej, ITB). So, for example, for transfer grating, guidelines can be found in the **EN 13141-1:2006**<sup>82</sup> standard with respect to its aerodynamic characteristics and noise reduction properties. There are no guidelines for the use of a particular grating model, and the choice is dictated primarily by aesthetics. Air grating is available in many shapes, colours and materials. The most popular air grating material is plastic; plastic grating is often selected for its low price. The rPP/NP, rPE (LD:HD - 30:70) and rPE (LD:HD - 50:50) composites produced during the project can therefore be successfully used as air grating materials.

## 5.5. Moulds for concrete testing

The suitability of concrete for use in building structures is assessed, among others, on the basis of compressive strength, flexural strength and splitting strength tests carried out in accordance with the guidelines specified by the **EN 12390** series of standards<sup>83,84</sup>. Information concerning the size and shape of samples for testing strength characteristics of hardened concrete is detailed in Part I of the **EN 12390** standard<sup>85</sup>. "Cube" type moulds are commonly used to create concrete samples with a standardized size. The Ceplafib project demonstrated the feasibility of using the



rPP/NP composite material to create a cubic mould for concrete testing with an edge length of 150 mm (inner size) compliant with requirements of the **EN 12390** standard <sup>85</sup> – Figure 12.



Figure 12 Moulds for concrete testing made of the rPP/NP composite.

## 5.6. Green roofs

With respect to green roofs, there are no dedicated European normative requirements. For the assessment of performance it is therefore recommended to use the guidelines included in the **CPR Regulation** <sup>26</sup>, the few national normative requirements, e.g. Swiss <sup>86,87</sup> or Italian <sup>88</sup> standards or national guides for design, construction and maintenance of green roofs <sup>89</sup>, such as the German **FLL** <sup>90</sup> or the British **GRO Code** <sup>91</sup>. The primary requirement for roofing is resistance to plant root overgrowth. This can easily be met by moulds made of rPP/NP composite materials, as demonstrated by moulds for concrete testing 5.5.

## 5.7. Surfaces for sports areas

One potential application of the recyclates is surfaces for sports areas. Surfaces for outdoor sports and recreational facilities should be fully tested for compliance with European standards concerning professional sports facilities:



- **PN-EN 15330-1:2014-02** Surfaces for sports areas – Synthetic turf and needle-punched surfaces primarily designed for outdoor use – Part 1: Specification for synthetic turf surfaces for football, hockey, rugby union training, tennis and multi-sports use <sup>92</sup>
- **PN-EN 15330-2:2017-10** Surfaces for sports areas – Synthetic turf and needle-punched surfaces primarily designed for outdoor use – Part 2: Specification for needle-punched surfaces for tennis and multi-sport surfaces <sup>93</sup>
- **PN-EN 14877:2014-02** Synthetic surfaces for outdoor sports areas – Specification <sup>94</sup>

The current European standards concerning synthetic surfaces for sports areas do not take hygiene and environmental requirements into account. The guidelines published by the International Federation of Association Football (FIFA) in the document titled "Handbook of Requirements. FIFA Quality Programme for Football Turf" contain general statements that pitch surfaces may not contain chemicals that are toxic, carcinogenic, mutagenic or toxic for reproduction when coming into contact with skin. Requirements concerning the content of selected chemical substances in materials can be found in the REACH Regulation, Annex XVII <sup>95</sup>.

National legislation also does not yet regulate the issue of hygiene requirements for surfaces, although work is underway to create appropriate regulations. When evaluating the impact of synthetic outdoor surfaces on the outdoor environment (soil and groundwater), it would be reasonable to refer to the requirements of German standards **DIN-18035-6:2014-12** <sup>96</sup> and **DIN-18035-7:2014-10** <sup>97</sup>. The test methodology described therein has been used in Germany to assess the various types of surfaces for sports areas since 1993. The current version from December 2014 involves determination of the following basic parameters of surfaces which have an impact on the environment: heavy metal content, total organic carbon (TOC) and polycyclic aromatic hydrocarbons (PAHs).



Table 8. Comparison of results of hazardous substance leaching tests (item 1.3) with requirements specified by the German standards DIN-18035-6:2014-12 [17] and DIN-18035-7:2014-10 [18].

Indicator name	Unit	Requirement according to [17,18]	Average value obtained				
			rPE (LD:HD - 30:70)	rPP	rPP/NP	NP	CF
Hg	mg Hg / l	≤ 0.001	4·10 <sup>-5</sup>	4·10 <sup>-5</sup>	4·10 <sup>-5</sup>	4·10 <sup>-5</sup>	4·10 <sup>-5</sup>
Cd	mg Cd / l	≤ 0.005	4·10 <sup>-5</sup>	4·10 <sup>-5</sup>	1·10 <sup>-4</sup>	1.44·10 <sup>-3</sup>	1.83·10 <sup>-3</sup>
Zn	mg Zn / l	≤ 0.5	4·10 <sup>-5</sup>	5.93·10 <sup>-2</sup>	3.27·10 <sup>-1</sup>	5.99·10 <sup>-2</sup>	5.51·10 <sup>-2</sup>
Total Cr	mg Cr / l	≤ 0.05	1·10 <sup>-4</sup>	1·10 <sup>-4</sup>	6.6·10 <sup>-4</sup>	6.6·10 <sup>-4</sup>	2.2·10 <sup>-4</sup>
Pb	mg Pb / l	≤ 0.025	4·10 <sup>-4</sup>	4·10 <sup>-4</sup>	4·10 <sup>-4</sup>	1.82·10 <sup>-2</sup>	2.82·10 <sup>-2</sup>
TOC	mg C / l	≤ 50	3.8	2.4	21.1	34.3	2.1

Results of tests of hazardous substance leaching from polymer materials do not indicate exceedance of permissible values specified in German standards **DIN-18035-6:2014-12** <sup>96</sup> and **DIN-18035-7:2014-10** <sup>97</sup>, which means that these materials may be used as elements of surfaces for sports areas in outdoor sports and recreational facilities.



## 6. Application potential of CEPLAFIB composites in other sectors

Mainly during the project implementation Action B4 - Replicability and transferability, consortium partners of CEPLAFIB project carried out several B2B meetings with external project stakeholders, where some of them already joined this community before the project start with their signed LOI (Letter of Interest), or they approached subsequently when they learned about the key outputs of our project initiative. The initiated interest of stakeholders, mainly represented by SMEs or start-up companies, but also some large entities, was triggered by the outstanding properties of our recycled composite materials, and the desire to test them in their own portfolio of products. CEPLAFIB Consortium perform several negotiation meetings with the interested future clients of CEPLAFIB materials and selected the most prominent ones by giving them a free sample of material or all the necessary technical support for producing a limited-edition series of their branded products made of our CEPLAFIB materials. The below described transferable initiatives were multiplied to several industrial sectors, namely, fast moving consumer goods (FMCG), electronical or ergonomic gadgets, automotive elements, articles for daily use, even children's toys and storage product commodities.

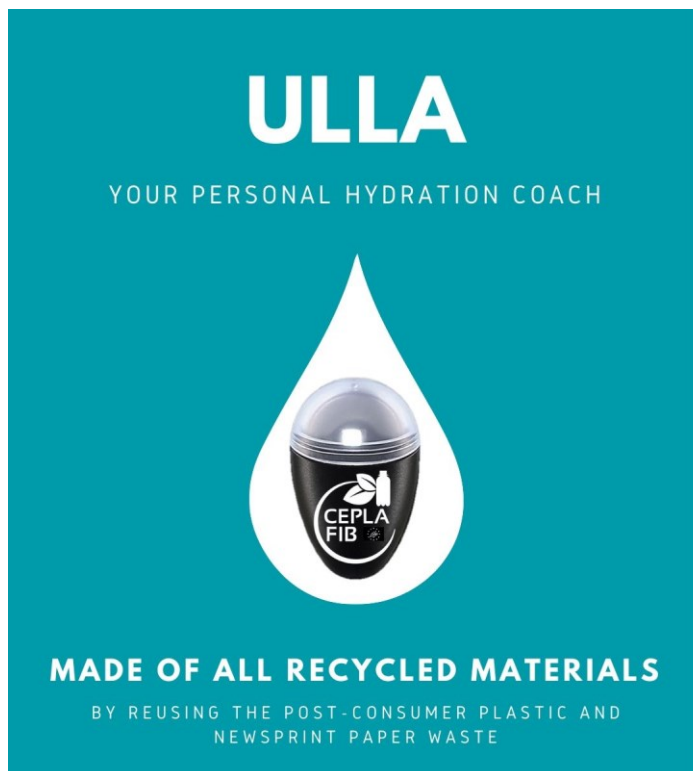
### 6.1. ULLA - Smart water hydration reminder now made of CEPLAFIB materials

The first transferable collaboration with external project stakeholders has been led by the project coordinator – TECOS in between November 2019 and January 2020. Recycled CEPLAFIB materials of type rPP/NP has been introduced to SME company Ulla Labs, located in Slovenia with an aim to be tested for housing covering of their innovative hi-tech product. A joint cooperation with Ulla Labs – a brand owner of smart and engaging contemporary wellness tool, entitled as simple as Ulla, has been swiftly established. Ulla employs drink detection, ambient and proximity technologies, and reminds, even motivates people to hydrate regularly with a subtle yet effective visual




alert. They say water is life, motivation is what gets you started, and habit is what keeps you going. A joint partnership follows the same vision, by firmly believing that Ulla, the hydration coach, is the missing link between all three.

Ulla device is originally made of virgin plastic material of type PP. With a common vision to introduce more environmentally friendly materials and to implement the circular economy with 3R (Reduce, Reuse, Recycle) concept prefix, a new alliance was born between Ulla Labs and CEPLAFIB project. We jointly created the first Ulla made of 100% made of recycled post-consumer plastic and waste paper. This limited primo edition of all recycled Ulla's was created through the LIFE CEPLAFIB initiative to demonstrate the cross-sectoral applicability of these new materials, which proves a lower environmental footprint, tends towards the plastic waste reduction, and promote the reuse of discarded plastic and paper.



**ULLA**  
YOUR PERSONAL HYDRATION COACH



**MADE OF ALL RECYCLED MATERIALS**  
BY REUSING THE POST-CONSUMER PLASTIC AND  
NEWSPRINT PAPER WASTE

**DRINK 3-TIMES MORE WATER  
BECOME HEALTHIER  
HAVE MORE ENERGY  
AVOID HEADACHES**

**Ulla - your personal  
hydration coach.**

- ✓ Reminds to hydrate if you forget
- ✓ Blinks before dehydration kicks in
  - ✓ Tracks when you drink
  - ✓ Fits on any water bottle
  - ✓ Fully automated.

Get more information on [www.ulla.io](http://www.ulla.io)



## 6.2. CEPLAFIB protective grasp elements for TAM-Europe buses

TAM-Europe is a Slovenian bus and commercial vehicle manufacturer with strong strategic commitment to product efficiency and environmental sustainability. Incorporating the knowledge and skills of a European manufacturer with over 70 years of experiences in the commercial vehicle industry, achieved by a highly qualified workforce and today strengthened through the benefits of integration into a multinational group with vast resources in the vehicle industry, TAM-EUROPE fulfils the highest product and service expectations. TAM-EUROPE makes buses, but unlike many companies in this sector it does so with a real understanding that every detail, however small, must be just right. This is especially true when it comes to the choice of materials from which the components of their buses are made.

TAM' Purchase Planning Logistics Team initiate the first contact with the CEPLAFIB project coordinator – TECOS and express their interest to test and to prepare a limited-



edition series of TAM protective grasps at handrails in airport bus shuttles. These elements must withstand the certain mechanical loads of passengers or better said their luggage, so they must be made of robust and high-quality plastic materials with above-standard mechanical characteristics. Since CEPLAFIB composites, thanks to the added reinforcements of newsprint fibers, can demonstrates up to 200 % higher modulus of elasticity and even up to 40% higher tensile strength than recycled or plain virgin polymers, are seemed to be a suitable alternative to the materials currently in use for such parts.

After several online consultation meetings TAM Europe has decided to establish an active cooperation with LIFE CEPLAFIB project. As TAM's core strategy is also strongly tied to environmentally friendly and, above all, sustainable materials, a new strategic alliance has been established and now a promo series of CEPLAFIB TAM Bus Elements has been produced and exhibited as another successful transferable project of external cooperation.

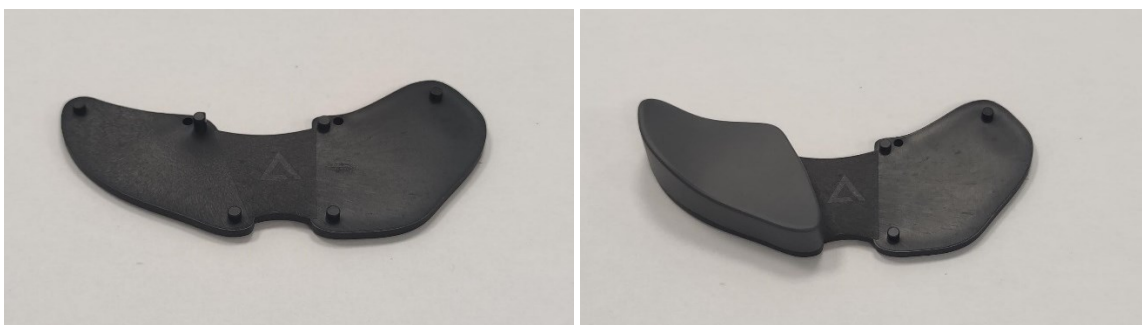
**TAM**



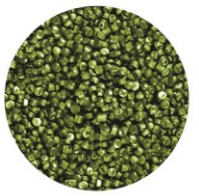
### 6.3. All recycled CARPIO – Ergonomic Wrist Rest

A young and very innovative start-up company DELTAHUB, situated in Slovenia, has designed and start to market a very sophisticated solution for people or employees who spent their working week behind a computer screen and keyboard. They designed an ergonomic wrist rest called CARPIO. In April 2019 CARPIO product received a Rector's award for the best innovation applied through Incubator of the University of Ljubljana. In March 2020 Deltahub has been selected as one of the top 5 Slovenian health start-ups, while in October 2020 Deltahub with their CARPIO innovation won the highest award for Innovation and a special award for start-ups by The Chamber of Commerce and Industry of Slovenia. Carpio is an ergonomic wrist rest that makes every computer mouse ergonomic and offers more healthier, stress- and tension-free working or gaming environment.

Deltahub contact CEPLAFIB Consortium after getting aquantified of our novel material solutions that are based on all recycled post-consumer ingredients, and express their interest to use CEPLAFIB materials for CARPIO padding. TECOS, coordinator of CEPLAFIB project, agreed with AITIIP to produce an extra batch of CEPLAFIB rPP/NP material grade, and set up a testing trial for limited edition series of CEPLAFIB CARPIO PADDINGS. The figures below present a successful implementation of already third transferable cooperation project with external project stakeholders.



Limited Edition CARPIO, where lower paddings are made of Ceplafib® rPP/NP material, while grey cushions are made of traditional TPE.

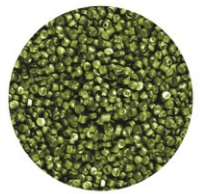




#### 6.4. CEPLAFIB Recycled Toys: From wasted yogurt jars to kids' playroom

CEPLAFIB transferable products reveals that recycling of post-consumer plastic waste can result in something tangible and meaningful. Through our project we manage to demonstrate that cups and jars from yogurt, ice cream, butter, just like the ones in your refrigerator and recycling bins, can ultimately end up back in your children playroom. While plastic packaging and single use plastic items are the primary ingredients in our CEPLAFIB materials, we sometimes integrate other types of recycled plastic that matches in colour (think white milk or yogurt jugs) when needed to ensure the best outcome products possible. All the post-consumer plastic waste streams for CEPLAFIB materials are collected by nearby waste management systems, and afterward sorted, grinded, washed, homogenized and reprocessed into our raw materials by waste plastic recycling company OMAPLAST. In the last stage the recycled plastic pellets are mixed with coloured masterbatches at TECOS just prior to injection and finally transformed into multicolour palette of building blocks for kids.





## 6.5. CEPLAFIB “stress-free” storage boxes

Every handyman knows how important it is to have his screws, bolts or nails in just the right place when creating its next invention. But getting organized can be overwhelming if you don't know where to start.

Creative storage boxes made of post-consumer plastic and paper waste can help to prevent your hardware & tools from rusting, organize your own workspace and offer an efficient and eco-friendly storage solutions. The little things make a huge difference, adding more space to your garage or basement workshop.

CEPLAFIB storage boxes represents another successful replication idea realized by TECOS that can help to become more organized, efficient and stress-free in your own workspace, while helping to protect the planet by incorporating recycled materials and green designs into your home.





## 6.6.CEPLAFIB shoehorn in your preferred color choice

Shoehorns come in all shapes, sizes and materials and while finding the right one is a matter of personal taste, using one is absolutely essential. Shoe horns prevent damage to the counter cap and keep your footwear good looking for the longest time possible. Shoehorns created from recycled plastic waste that comes from your trash bin could be your own circular choice.

Meet our CEPLAFIB shoehorns, made of post-consumer recycled plastic, of just the right size for every woman's handbag or men's jacket pocket in your preferred colour.

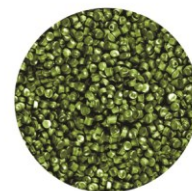
This transferable project was realized by TECOS – CEPLAFIB Coordinator.





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