**Table 1**. Main types of bio-based products

| **Biomaterials by category** | **Type of bio-based products** | **References** |
| --- | --- | --- |
| **Category 1**Binding materials, aggregates and/or additives for soil, cement and/or concrete | Sustainable cement Green, ecological and/or sustainable concrete Concrete blocksHardened concreteAgro-concrete/cementOrdinary Portland cement (OPC) concreteLightweight aggregate concreteCement concreteGeopolymer concreteClayey sand and soilCement mortarsActivated cement mortar Cement-based panelsWood-cement blocksRoofing tilesClay and laterite soils | [7, 18, 54, 56, 63, 67–70, 72, 73, 76, 22, 82, 84, 87, 89–91, 93, 100, 23, 27, 36–38, 52, 53] |
| **Category 2**Brick materials | Ceramic bricksClay bricksClay matrix bricksFired clay bricksAgro bricksEarth bricksLight fired clay bricksLightweight bricksThermally efficient burnt clay bricksEco-friendly clay bricksEco-friendly porous ceramic bricksUnfired earth blocks/ bricksWhite brick fuel cellBuilding block for masonry wall | [6, 15, 77, 78, 80, 86, 97, 101–105, 26, 31, 38, 43, 55, 57, 59, 64] |
| **Category 3**Materials/biocomposites for structural and/or reinforcement applications | Natural fiber/polymer composites (NFPCs)Polymer matrices for lightweight structural applicationsReinforced polypropylene composites (wall panel)Bio-epoxy resin reinforced green compositesBio-based polymersWallpaperHybrid polypropylene composites False ceiling tilesFiber-cementConcrete walls Cement-bonded particleboardBinderless fibre-boardReinforced polypropyleneReinforced composites ParticleboardFibreboardsUnitary (or ‘‘monolithic”) structural components and assembliesEarth Plaster CompositesPanels, door shutters, door frames, roofing sheets and dough molding compoundsRoofing tiles, ceiling plates, thin sheets, wall panels Lightweight building componentsStructural sheathing materialsComposite boards/panels | [30, 43, 106–113, 57, 58, 61, 79, 83, 96, 99, 100] |
| **Category 4**Materials for thermal and/or acoustic insulation in buildings | Joints between walls, windows, floor, and roofRecycled waste panelsInsulation panelsBio-based insulationsStructural materials for low-energy buildingsThermal insulating plateReinforced panelsParticleboardsBio-Based Plastics | [14, 31–33, 62, 66, 98, 110, 114] |
| **Category 5**Road construction materials | Sustainable bio-modified asphaltAsphaltic concreteModified Asphalt Binders | [81, 95, 115, 116] |

**Table 2.** Main properties and parameters of the bio-based products

|  |  |  |
| --- | --- | --- |
| **Properties** | **Parameter** | **References** |
| **Physical**  | SorptivityBulk densityMicrostructureSpecific Gravity Drying shrinkageApparent PorosityWater absorption | [6, 7, 55, 58, 61, 64, 65, 77, 78, 80, 81, 88, 14, 89, 91, 92, 95, 97, 98, 100, 102, 104, 105, 15, 106–110, 112, 114–116, 22, 25, 28, 32, 35, 53] |
| **Mechanical** | DurabilityWorkabilityFlowabilityFlexural strengthTensile strengthImpact strengthYoung’s modulusThickness swellingCompressive strength | [6, 7, 32, 35, 36, 38, 53, 57, 58, 61–63, 14, 64, 68, 70–75, 82, 88, 15, 89, 91–94, 96, 97, 99, 100, 102, 18, 103–109, 111, 113, 114, 22, 116, 26–28, 31] |
| **Chemical** | Loss on ignitionChloride resistanceResistance to chlorideAcid and sulphate resistanceHeavy metals content/leaching toxicity | [7, 18, 22, 25, 28, 53, 55, 64, 78, 98] |
| **Others**  | Mineralogical analysisSound absorptionThermal conductivityHigh temperature resistanceThermogravimetric analysis | [6, 7, 59, 62, 64, 68, 73, 77, 78, 92, 98, 99, 14, 100, 102–107, 109–111, 26, 114, 31–33, 38, 55, 57] |

**Table 3.** Main types and properties of AWBs used by category

| **Type of biomaterials** | **Main type and form of AWB** | **Main characteristics of the by-product** | **Effects on the properties of bio-based products** | **References** |
| --- | --- | --- | --- | --- |
| **Category 1**Binding materials, aggregates and/or additives for soil, cement and/or concrete | Rice Husk (Ash)Sugarcane bagasse (Ash)Coconut husks (Ash) | Rich in amorphous silicaHigh pozzolanic activityPore-forming additivesLower specific gravityIncreases setting timelower thermal conductivity | Improved mechanical properties (Compressive, flexural, shear and tensile strength)Reduction of thermal conductivityDensity reduction (lighter materials)Better resistance to acid attackIncreased resistance to chloride penetrationLower water absorptionReduced permeabilityImproved durabilityImproved workability Improvement of the geotechnical properties of the soil | [6, 7, 35, 38, 52, 53, 56, 60, 63, 67–69, 15, 70–72, 74, 75, 82, 90, 92, 113, 18, 22–24, 28, 31, 34] |
| **Category 2**Brick materials | Rice Husk (Ash) Cereal Straw (Ash –fibers)Sugarcane bagasse (Ash) | Increased ceramic strengthIncrease in amount and size of pores Reduction of bulk densityReduction of brick weightReduction of the thermal conductivity coefficientLower dead loadImproved thermal insulation propertiesImproved static properties Reduced plasticity | [15, 26, 104, 105, 31, 55, 59, 64, 77, 78, 80, 102] |
| **Category 3**Materials/biocomposites for structural and/or reinforcement applications | Cereal Straw (Fibers)Rice Husk (Ash)Coconut husks (Fibers - Ash) | Lower specific gravityHigh percentage of fibersLonger fibersTubular internal structure, strong and efficient Low densityHigh cellulose and hemicellulose content | Improvement of impact, tensile and flexural strength Better resistance to water and thickness swellingLow weightGood sound absorption Improved load transfer and crack arrest efficiencyImproved thermal insulation/ thermal stabilityBetter structural integrity and energy dissipationGood stiffness for civil infrastructural applicationsControl of shrinkagecracksDecreases erosion of materialsImproveds shrinkage propertiesBetter absorption of impact energy | [15, 30, 108–112, 114, 57, 58, 61, 83, 96, 99, 100, 106] |
| **Category 4**Materials for thermal and/or acoustic insulation in buildings | Rice Husk (fibers)Cereal Straw (fibers)Sugarcane bagasse (fibers) | Better thermal and environmental performanceGood thermal conductivity and resistivitySatisfactory results in mechanical and thermophysical performanceHigh sound absorption coefficientsLower density | [14, 31–33, 66, 98, 114] |
| **Category 5**Road construction materials | Rice Husk (Ash-fibers)Coconut Shell(Small aggregate)Sugarcane bagasse (Fibers)Palm shells(coarse aggregate) | Increased resistance to thermal cracking of the pavement at low temperaturesReduced permanent (plastic) deformation at high road surface temperatures under traffic loadsImprovement of -the rutting factorImproved fatigue resistance of the asphalt binderGood range stability MarshallImproved mechanical properties | [81, 115, 116] |

**Table 4.** Limitations and improvement alternatives for bio-based products

|  |  |  |
| --- | --- | --- |
| **Limitations and/or disadvantages** | **Alternatives to reduce adverse effects** | **Reference** |
| Increase LOIReduction of workabilityLower strength activity index (SAI)Higher drying shrinkageHigh water absorptionSusceptibility towards chemical attackEffect of moisture content on internal bondingDimensional stabilityLower durabilityCrack formation | Additional treatmentsChemical and/or heat treatment of fibresPre-treatment methods (screening, burning, drying, firing)Incorporation of nanomaterials nano silica, nano aluminaInclusion of bacteria in rice huskAddition of stone dust | [15, 18, 54, 58, 62, 91, 106, 107, 110–112, 114, 21, 22, 25, 29, 31, 32, 34, 35] |

**Table 5**. Main benefits by dimension

| **Dimension**  | **Description of main benefits or advantages** | **References** |
| --- | --- | --- |
| Economic | New value chains New market opportunitiesSavings raw materials Reduction of material production costs Reduction of waste landfill feesReduction of transportation costsReduction in construction costReduction of road construction and maintenance in rural areas costs | [7, 15, 55, 58, 60, 64, 67, 70, 74, 82, 85, 86, 23, 91, 96, 97, 99–101, 105, 107, 115, 26, 28, 29, 31, 32, 37, 42] |
| Environmental | Carbon dioxide (CO2) emissions reductionReducing global warming and climate changeIncreasing energy efficiencyReduction in consumption of thermal and electrical energyLandfill reductionImproving the management of the AWBRecycling and valorisation of AWBValues of leaching toxicity much lowerReduced consumption of natural clay reservesReducing the exploitation of natural resourcesReduction of AWB burningReduction of water consumptionReduced consumption of virgin raw materialsReduction of soil erosion | [6, 7, 32–38, 42, 52, 54, 14, 55–58, 63, 64, 66–69, 15, 70, 72–78, 82, 83, 23, 85–87, 91, 94, 97–101, 24, 103, 105, 106, 108, 111, 114, 115, 26, 28, 29, 31] |
| Social | Creation of new jobsEnhancing the economic power of local communities.Low-cost building and/or infrastructure development in low-income regionsUse of locally available materials for infrastructure works in developing countriesReduce social housing costFunctional, high quality, comfortable and affordable environments for building occupantsSocietal welfareHealthy indoor environmentPopulation health benefits |  [14, 31–33, 87, 91, 93, 100, 105, 115] |

**Table 6.** European Union projects

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Proyect name** | **Objetive** | **Type of AWB** | **Type of bio-based prodcuts** | **Project implementation date** | **R** |
| Grant agreement ID: CR147691-BRE21154 | Development of new construction materials based on mineral binders derived from waste | Straw and husk | Mineral binder | May-July 1994 | [117] |
| ECO-PCCM | To introduce a new class of eco-friendly and cost-effective polymer composite construction material | Rice straw, hemp, kenaf, cotton, sisal, flax | Renewable eco-friendly composites for structural components | October 2004 -September 2007 | [118] |
| SYNPOL- Biopolymers from Syngas Fermentation | Establish a platform for integrating synthesis gas production and fermentation technologies for cost-effective commercial production of high value-added biopolymers. | Straw | Biopolymers | October 2012 -September 2016 | [119] |
| REHAP | Development of new materials for the construction sector from agricultural and forestry residues | Wheat straw | Thermoplastic PU AdhesiveWooden boardsCement | October 2016 -March 2021 | [123] |
| AgroCycle | To convert low-value agricultural waste into highly valuable products, achieving a 10% increase in waste recycling and valorisation by 2020. | Horticultural waste | High value-added biopolymers | June 2016 -May 2019 | [128] |
| Mycotaff | A renewable bio-based material that enables efficient, cost-effective production of high-quality insulation, packaging, dry-wall, and other building materials | Mushroom mycelia | Prefabrication wallsmaterial for insulation and other building applications | June -september 2018 | [129] |
| BARBARA | The development of novel bio-based engineering bioplastic materials to be validated as functional prototypes with advanced properties for the building and automotive sectors. | Lemon, carrot, pomegranate and almond shell | Polyester-Based BiocompositesMoulds for Resin Transfer Moulding and truss joint prototypes | May 2017-October 2020 | [130] |
| B-SMART | To develop new intelligent cementitious nanocomposites for multifunctional built infrastructure made by combining ordinary Portland cement (OPC) with cheap bio-nanomaterials synthesised from root vegetable waste such as carrot and beetroot waste streams produced by the food processing industry. | Carrot and beetroot waste | Intelligent cementitious nanocomposites for multifunctional built infrastructure | September 2018 - September 2020 | [131] |
| NoAW : No Agro-Waste | To generate innovative efficient approaches to convert growing agricultural waste issues into eco-efficient bio-based products opportunities with direct benefits for both environment, economy and EU consumer. | Maize silagegrape stalksVine shoots /wine pomaceFruit and vegetable wastes | Biocomposites/Biodegradable polymers - polyhydroxyalkanoates (PHAs). | October 2016 -January 2021 | [124] |

R: Reference