BioGecko Vol 12 Issue 03 2023

ISSN NO: 2230-5807

Study of sustainable high-performance polymers for additive manufacturing

Swara Gokhale[1*]
[1*]Indus International School, 576, Bhukum, Tal, Mulshi Rd, Pune, Maharashtra 412115

Abstract
Polymers encounter several problems in terms of processability, strength, physical and chemical properties, functionality, stability and applications. In this concern, Additive Manufacturing (AM) is seen as a rapid prototyping and alternative manufacturing method, commonly known as 3D printing. There is currently anincreased interest in the safety of AM methods and the things that are accessible to use. Advances in manufacturing technology and polymer materials offer many opportunities for more efficient production, such as raw materials, trash from the end of life and ecological synthesis.This outline offers a concise synopsis of polymer additive manufacturing technologies, sustainability of polymers in additive manufacturing, and developments in degradable/recyclable polymers in additive manufacturing. It also provides insight into the important role of additive manufacturing in the industrial, chemical and digital manufacturing industries in the future. Polymers that are used for medicinal purposes that breakdown naturally for use in biology are not subject to this review.
Keywords: Additive manufacturing; Polymers; 3D printing; Sustainable polymers; High-performance.

1. INTRODUCTION

Our world today is filled with incredible technological and scientific advancements, as well as the unanticipated consequences of these developments, are shaping our future. The sole distinct and extreme example is given by synthetic polymers, which have seen tremendous development since the 1950s. While synthetic materials have numerous benefits, their durability has also led to the worldwide plastic pollution crisis, which is currently one of the biggest risks to the health and future of our planet and its inhabitants. [1].Polymer products represent approximately 9% of the $1.2 billion market segment and 30% of injection moulded products. Injection moulding is basically a process of manufacturing that can produce large number of products, however due to the process related to waste treatment after injection moulding process has considerable adverse impacts on environment.Recent developments show that 3D printing has the potential to replace injection moulding in many areas (Campbell et al., 2012).Additionally, some estimate that additional production could save a million tons of CO_2 emissions and energy savings of up several joules by 2025 [2]. However, there are other efforts to develop additional manufacturing processes that reduce environmental impact.

It created a need for high-efficiency, low-performance and powerful devices, which led to a sharp rise in AM product development. Yet, most of these products are not intended for use for recycling. There is a need to develop effective materials and processes to process recycled materials. In addition to material, product performance can be further enhanced by geometry. Thanks to its unmatched power-to-weight ratio which eliminates the dependency of weight to decide how much power will be generated according to its weightand the ability to obtain excellent materials while reducing waste materials in production and all the way.

In fact, additive manufacturing enables the "dematerialization" of products in a way that injection moulding is not possible, using lattice-like geometries where injection moulding is not possible. The architecture allows the product to be made from a single material so that it has many mechanical properties. When looking at practical applications such as cars, many different materials are used in complex assemblies, the strength required for each part of the approximately 40 different polymer cars that have been temporarily developed over the years rather than co-design first with sustainability to achieve the mechanical amount. The diversity of automotive components makes recycling very difficult. However, we believe that many types of polymer materials can be replaced with small amounts of polymer composites;allchemicals used can be recycled. The limitations of the objects selected here can be achieved by cutting the geometry of medium-sized 3D-printed models overcome or trellis to achieve similar or better functional diversity.

In addition to correcting the geometry of the material, the choice of polymer materials is special because they are able to maintain desired qualities when subjected to extreme circumstances like heat, pressure, stress, or caustic substances. Since polymeric materials can be created to endure weathering for an extended period of time, they are an excellent option for many industries, including aerospace, automotive, and construction. High-performance polymers, however strong to heat, chemicals, and/or stress, can be difficult to renew and compost. The same product is designed for collision work with depolymerisation chemistry. More than 20% of all plastics produced worldwide and 50% of all polymers used in production are thermoset polymers that have gone through molecular and thermal cross-linking.

While additive manufacturing can reduce waste, energy consumption and CO_2 emissions compared to conventional polymer manufacturing, it cannot solve the problem of unsustainable production. Our understanding of technology's negative impact on the environment continues to evolve, so the design of high-performance products must have a vision for end-of-life, treatment and reuse or recycling. Although there are many good ways for additive manufacturing to support sustainable development principles, there is still a great need to ensure that additive manufacturing products themselves are recyclable or compostable materials.

Here we will focus on polymers useful for additive manufacturing. This examination does not apply to materials that decompose used in biological uses or for medicinal treatment.Focusing on high-quality polymers, this publication reviews current additive manufacturing methods, the currently degradable polymers used in each of the additive manufacturing processes below, and then discusses the impact of this information on humans.

2. CONTEMPORARY METHODS FOR ADDITIVE MANUFACTURING

Additive manufacturing 3D printing was first documented in 1981 by Japanese inventor Hideo Kodama, who developed a method for creating 3D models by treating layers of photosensitive resin with ultraviolet light[3]. Many materials have been used for AM in recent years: ceramics[4, 5], metals [6, 7], hydrogels[8, 9] nanomaterials[10, 11], pharmaceuticals [12, 13], and even biomaterials such as cells and tissues[14, 15]. However, polymers are still the most popular materials for additive manufacturing due to their ease of processing, good manufacturing technologies, various thermomechanical properties and chemical inertness[16, 17]. There are four main types of processes for the additive production of polymers: extrusion, vat photopolymerization (VP), binder spraying, and powder bed fusion. For each type of additive manufacturing, the materials required and the complex processes associated with each additive manufacturing are briefly described below.

2.1 Extrusion

Extrusion-based additive manufacturing (EB-AM) is a 3D manufacturing process in which material is heated and removed from the nozzle, leaving one layer at a time. It uses two types of technologies: filament and pellet extrusion. Filament extruders are required to convert raw plastic pellets into filaments; therefore, the products used by these machines are limited. Pellet extruders are more machines that use screws in the barrel. In addition to their complexity, pellet extruders offer lower price, faster speed and more equipment to use.These outflow methods are cheap, but they have a relatively small number of uses since they require a rasterized deposition nozzle to construct each layer and settlement, and their capacity is constrained by competition to start/stop the extrusion of solids. Due of weak interlayer bonding caused by cooling and extrudate solidification, FFF systems also experience substantial anisotropy. The basic diagram for material extrusion is shown in Figure 1.

ISSN NO: 2230-5807

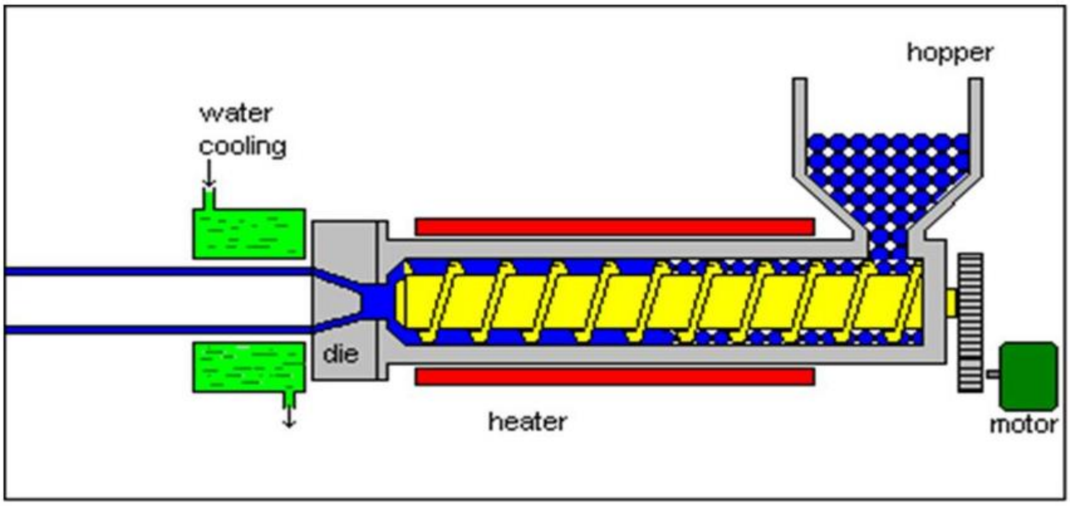

Figure 1: Basic process of material extrusion

2.2 Binder Spray/Binder jetting

Binder spraying is an additive manufacturing process that injects a binder into the powder. This creates great value, one of the products and tools made of metal, sand, ceramic or composite. The process involves laying down layers of material, creating a solid object one layer at a time. Binder Spray is an additive production process that uses specifically selected droplets sprayed and light cured to form the product. In binder spraying, the starting material must have a very low viscosity (<0.1 Pa s) and a high stress to be able to spray picolitre droplets to form good primitives of the design.While sputtering provides precise spatial control (~50 μm) of many resins in one configuration, the rheological limitation of sputtering limits product selection for low-viscosity, low-molecular-weight precursors. The basic operation of binder spray is shown in Figure 2.

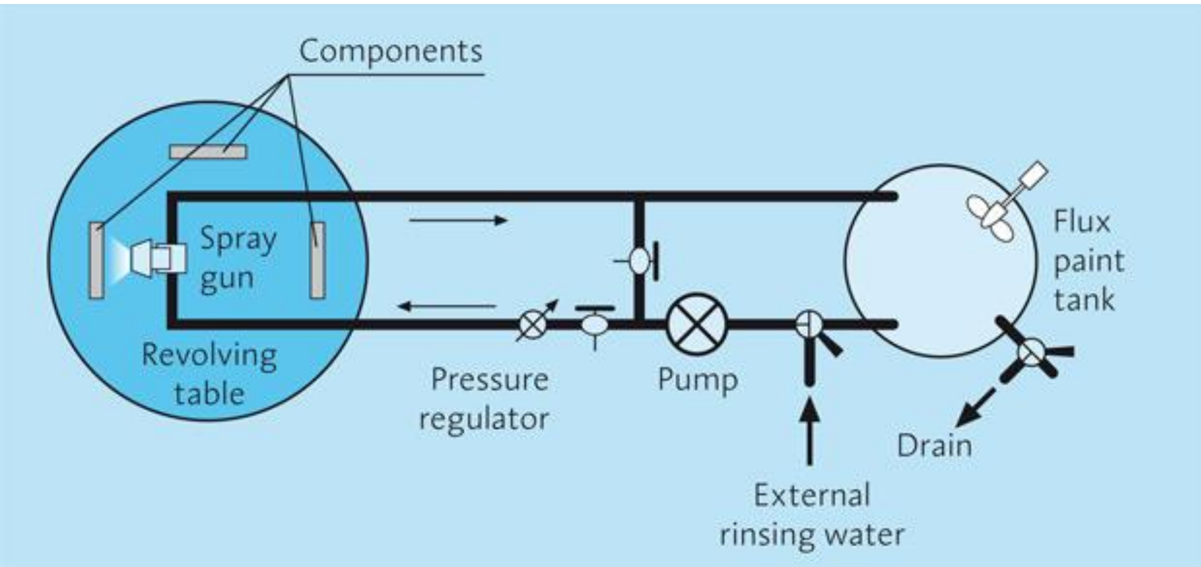

Figure 2: Basic process for binder spray

2.3 Powder bed fusion process (PBF)

Powder bed fusion process is one of the technologies related to additive manufacturing. It follows the principles of production layer by layer and their fusion. The heat source focuses its heat on the powder substrate and heats a selected section. As a means of heating, sources such as laser beams, electric rays and infrared rays are used. The heating process assists the powders to take up a shape of intended object. Powder bed fusion process can be used to process metals, ceramics, polymers, composites and other similar engineering materials. This technology is widely used in aviation, energy sector, transportation and many other industries.Thepowder bed fusion process involves selective fusion of the powder Polymer powder bed. When using powder starting material, mixing and to provide a narrow polydispersity of sizes for high resolution. Making 30–50-micron powders from high quality polymers has proven difficult and wasteful [18]. In addition, the thermal stability and recyclability of powders are often limited, resulting in substantial waste. Although P-PBF is used to produce the final product, it has (1) limited material usage, (2) limited efficiency due to heating/cooling, (3) post-processing weight (dust removal), (4) energy consumption, (5) generation of large amounts of waste (due to weight of deterioration by oxidation from temperature cycling and/or polymer molecular development), and (6) difficulty to process numerous files at once. The basic operations in P-PBF are shown in Figure 3.

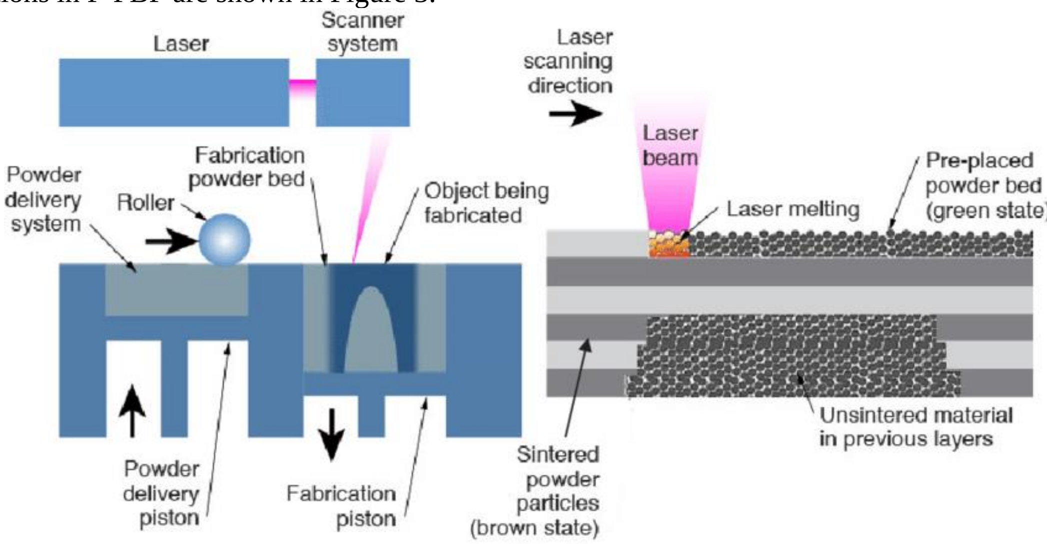

Figure 3: Basic operations in PBF

2.4 Vat Photopolymerization (VP)

Vat photopolymerisation is a resin-based related process of additive manufacturing, in this process ultraviolet light is employed to solidify the liquid resin layer-wise into the required 3D shape. In cases where the resin is a formulation which is dual-cured it will be thermally cured to achieve its end properties, which is either an elastomer or a thermoset.There are three generations of chemical and photopolymerization content for UV-curable liquid resin-based AM. In the initial phase, stereolithography (SLA), also known as photopolymerization (VP), was used to create objects baths of liquid resin are spatially light-cured by scanning the laser dot position [19].The second VP type, called digital light projection (DLP), uses high-speed UV projected images across the whole of X-Y Just one shot of the bath's plane [20], which contains liquid resin. A layer of oxygen-enriched liquid resin is constantly added to the third generation of VP, sometimes referred to as Constant Liquid Interface Growth spread over the design to provide a growth liquid interface (dead space) that inhibits polymerization. CLIP can print 25 to 100 frequencies faster than conventional production processes, at speeds up to 3000 mm h^{-1}, with different types of motion of the platform and UV irradiation and different window configurations [21-24]. Although CLIP is currently limited to low viscosity,unlike other 3D printing techniques like Fused Filament Fabrication (FFF) and Powder Bed Fusion (PBF), CLIP can create isotropic items at viscosities up to roughly 2500 cPe.g. biomedical devices [25-27]. Basic operations in Vat polymerization is shown in Figure 4.

BioGecko Vol 12 Issue 03 2023

ISSN NO: 2230-5807

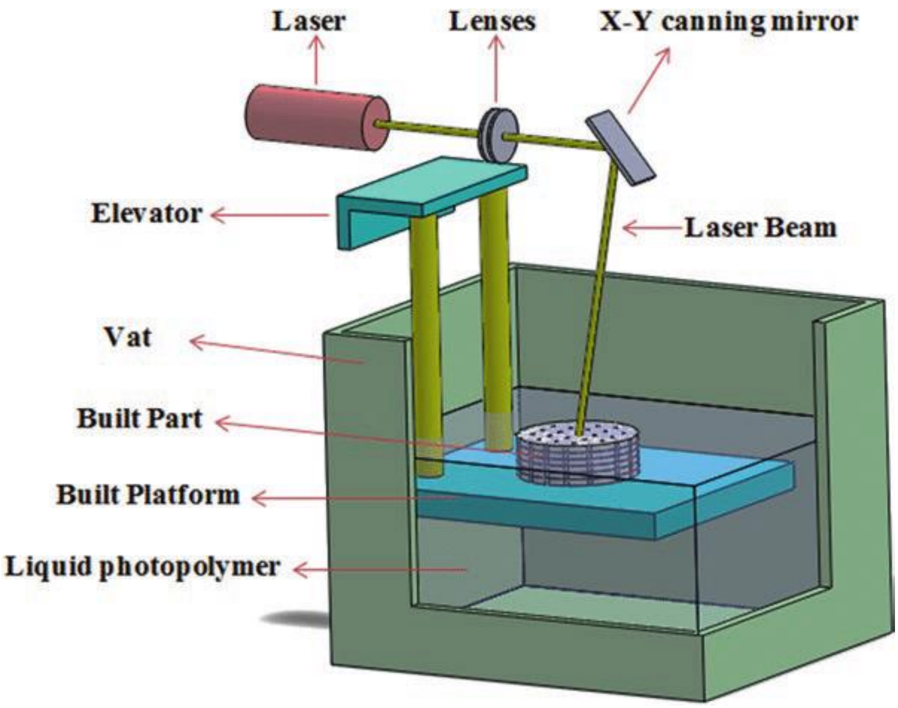

Figure 4: Basic operations in Vat polymerization

3. STABILITY OF ADDITIVE MANUFACTURING POLYMERS

New materials are often developed to improve existing materials for special purposes and often seek to enhance qualities like courage, hardness, tolerance of temperature parameters, and resistance, or even make them better than their competitors. The focus on the meeting of requirements for specific uses or creating composite materials for competitive market resins has led to the development of best knowledge for effective use, but has also caused global stress; including growth coexistence of many different materials complicates the collection, separation and recycling process. Looking ahead, data scientists, engineers, and policymakers must consider the whole picture of data development and the needs of data throughout its lifecycle. Key elements of sustainable development discovered include: (1) reagents and feedstocks (including raw materials from renewable sources), and (2) new polymeric materials intentionally designed to include degradability or reprocessing to preserve the material from access to waste and water.

In AM materials, the circular economy idea serves as an outline.The creation of new materials and the reuse and recycling process particularly, degradation is a useful tool for building social sustainability/relationships. Any polymeric material can be collected and broken down into its components to form products. This will increase the value of the raw material above the initial production and help the business cycle [28-30].Designing an equipment or innovation designed to improve quality of life using local materials will providesocial security for millions of people from economically struggling countries worldwide.

3.1 Designs for Degradability and Recyclability

Decomposition occurs in many forms and can be divided into two categories include induced degradation and passive degradation. Passive degradation happens when an item can deteriorate naturally in its environment without the help of specific agents.It can occur on the body, such as stitches that normally break when it comes into contact with the body, or outside, such as in landfills, where sunlight and oxygen are exposed to ultraviolet light. The chance for passive degradation to address plastic pollution through limiting the existing lack of recycling makes it a compelling topic for polymer development. This exhibits the benefit of passive compostable breakdown, so products may degrade further even if they are not identified and collected in appropriate waste management facilities. However, even polymers designed to be biodegradable or compostable materials do not degrade due to a lack of water or oxygen in landfills[31]. Another major challenge in decontamination is the quality measurement of mechanical properties and maintaining chemical inertness over the intended lifetime, but still achieving the time required for natural disasters and safety.The conditions under which passive degradation occurs are assumed to be different from the conditions in which the polymer is used.

As an alternative, degradable polymer can offer the characteristics and durability needed for usage in various applications.Decay activation involves the presence of "switches" that can initiate deterioration or deterioration of the product in conditions perpendicular to its use. This may include replacing the catalyst, adding solvents, or other external factors.

The role of the catalyst is to participate in the slow stage of the reaction and reduce the activation energy. If you lower the activation energy, more molecules will have enough energy to collide properly to form the products, and therefore the reaction will be faster. At the end of the reaction, the catalyst will return to its original state. By replacing the existing catalyst with synthetic catalyst may aid in degradation. For examples, recently Layered double hydroxides (LDH) based catalysts are seen to have better degradation of towards organic pollutants, pharmaceuticals, aromatics, chemical residues and similar compounds by activation of peroxymonosulfate (PMS).

Solvents plays a crucial role tailoring the properties of materials that is synthesized, the solvent chosen must be capable of dissolving the polymer, swell any particle added in the composites and should also disperse able capable of dispersing the discrete particles evenly in the polymer matrix. The key parameter for solubility of polymer in solvent and the also its degradation in environment is chemical composition of the solvent used. The solvent employed must be such that it should be capable of over-ruling polymer-polymer interactions in order to dissolve polymer segments.However the solvent used is mostly organic (VOC's) and are considered to be harmful to environment, hence recently much research is focused on use of combination of solvents with non-solvent e.g., (acetone-water) to minimise the adverse effects as well as aid in degradation of polymer in environment. Some other factors such as heat and electricity also can affect the degradation of polymers.

Research of high-quality polymers is drawn to breakdown because it offers a chance to produce products that, when the product serves its purpose, can compete with existing polymers in terms of performance and lifetime when newly recycled [32]. However, one of the challenges in this field is the lack of large-scale systems that can support the recycling of different types of polymers. Some of the chemical processes also include electronic products, such as breaking down or grinding the material into products that are easier to recycle.

3.2 Material Extrusion

The moulding of rigid polymer melts serves as a basis for fabrication goods, most of which are easily reprocessed. One of the most widely used materials for FFF is polylactic acid (PLA), a biodegradable and renewable aliphatic polyester. PLA has reduced hazard compared to materials produced from oil raw materials and higher production costs, but its poor properties from autohydrolysis to lactic acid make it popular as a safe and durable material [33]. Since the rate of degradation of Adapting to its surroundings, PLA (as a compostable substance) many efforts have been made to improve its degradability and mechanical properties. This has led to the development of different types of Specific instances of PLA comprise poly(l-lactic acid) (PLLA) and poly(d,l-lactic acid) (PDLLA) [34].

In addition, PLA combines PGA, or polyglycolic acid, is a chemical to form a copolymer poly soluble in acetone, ethyl acetate, THF and other solvents. Modification of thePLA polymer chain allows modification of the product beyond degradation, such as improving the hardness and heat performance of the material for further use. For example, poly(l-lactide-co-ε-caprolactone) (PLC) is a more elastic copolymer than PLA and has a higher degradation rate than poly (PCL) [35]. In addition, Appuhamillage et al. Combining PLA with a strong Diels-Alder functional polymer to create a recombined material for extrusion-based printing has been shown to increase the material's stiffness by more than 200% [36]. PLA blends, blends, and composites are particularly useful as they allow modification of elastic modulus, yield strength, and maximum strain without the need to develop a new synthetic process. Other polymer blend filaments forFFF include packaging materials and materials such as polyolefins, polystyrene (PS) and polyethylene terephthalate (PET). Problems integrating post-consumer waste into AM resins or raw materials arise from inconsistency of polymer flow and the difficulty of recycling each product.

With the development of science and technology, many degradable materials can be produced or modified for further production. Recently, the addition of polyetheretherketone (PEEK), an all-thermoplastic material used in high-performance applications such as bearings, piston components, and compressor plate valves, has improved FDM tools. 3D printing had not been made since the 1980s until 2015, when FDM technology could be adapted to print what was needed to print high-temperature filaments [37]. This is just one example of how advances in additive manufacturing have led to the use of different materials; Other developments in Ongoing release of AM recyclable melts and other plastics annually. In building materials, instead of cement in the size of extrusion products, “geopolymers” are starting to move to other green areas at AM [38,39].Geopolymer combines waste-collected fly ash and slag, creating a low-quality material combination and has been shown to have properties comparable to conventional cement [40]. Recycling of geopolymers was also studied and showed good results, but more research is needed to improve the recycling process [41].

Various components can be repurposed for further productioncomprising the recycling of product grade thermoplastics from containers into low-cost products [42] through extrusion-based additive manufacturing and the use of by-products like wheat,, flour and sawdust as fillers in thermoset resins. The use of recycled materials in AM filaments also has a positive impact on the later life of the product, the use of waste that can affect significant costs for collecting and transferring [43]. Investigation on sustainable materials for extrusion equipment has mainly concentrated on cost savings, waste reduction, raw materials, and later integration of waste materials, rather than producing Recyclable thermosets, because the extrusion's current state equipment relies mostly on thermoplastics for prototype development for the business application form.

A breakthrough in thermoset materials for extrusion technology is the use of the Diels-Alder Reversible Thermoset process(DART), where reversibly crosslinked polymers can be 3D printed to increase product durability and reduce anisotropy [44]. Similar to Appuhamillage's work on PLA, Guo et al. (2021) used a Diels-Alder network to create reusable and recyclable materials that can be 3D printed. Printed materials can withstand high humidity, salt water and ethanol, heat up to 100°C. Elastomers can also retain their mechanical properties by at least three processes to regenerate [45].

Similarly, Shi et al. (2017)developed a thermoset.The thermomechanical properties of the vitrimer epoxy ink for direct writing are almost similar after at least four reuses after its dissolution in ethylene glycol at 180°C [46]. The use of covalent adaptive networks is an efficient way to create vitrimer materials that can be easily fabricated in AM. Instead of completely breaking down and repolymerizing the polymer, reprocessability can be put into thermosets using heat or catalysts.

Another recent development in the literature useful for extrusion materials is the use of thermosetting poly(dicyclopentadiene) (p(DCPD)) and degradable comonomers by Davydovich et al.(2022) [47]. DCPD is a rigid thermosetting plastic commonly used in automotive applications such as body panels and packages for trucks, buses and construction equipment. Davidovic et al. (2022) showed that addition of dihydrofuran (DHF) to DCPD resin reduced printed DCPD to oligomeric products with approximately 80% product recovery. Printed materials also have a final strength of about 35-40 MPa. Additionally, using front-side polymerization to harden thermosets during printing reduces the energy required for thermoset production.This high temperature process, which decomposes into functional oligomers, is a promising product for the chemical industry.

ISSN NO: 2230-5807

3.3 Equipment / Binder Spraying

Like extrusion equipment, the most common materials used in spray equipment are thermoplastic materials that can be recycled, but also thermoset photopolymerizable resins and elastomers suitable for high performance[48].Prepolymers, such as a mixture of high and low molecular weight acrylates and methacrylates, which can form hard materials, are typically used to create thermoplastic resins for plastics or adhesives. However, few studies have developed polymers specifically for recycled materials or solid materials or sealing jet. The use of heat to reduce the viscosity of materials is limited to thermally induced marriage of the prepolymer, but the creation of degradable photopolymer chemistry over AM will ultimately result into jetting of materials [49].

3.4 P-PBF, or polymer powder bed fusion

A new technique called Polymer Powder Bed Fusion (P-PBF) fabrication as it mainly uses semicrystalline thermoplastic prepolymers; material is usually Nylon 12, but other. Polymers such as Nylon 6, Nylon 10, Nylon 12, ABS, PS and PC are sold [50]. The selection of polymers useful for P-PBF is limited due to the high powder content of the job. Most research on the stability ofP-PBF has focused focus instead on enhancing the ability of powders and binders to be recycled. To decrease waste and the expense of using raw resources, the majority of wheat flours are collected, refined, and then reused. White powder recycling, however, has its own difficulties.

The powder will have defects caused by temperature and sintering outside the printing area, and the polydispersity of the particle size generally increases after processing, causing the product to be different aged [51]. Even dust from the same batch after the same number will show different degrees of degradation depending on the proximity of the powder to the place of manufacture [52]. Also, the nature of PBF leads to cross-contamination and dust separation when printing with a variety of materials. To address these issues, Kumar and Czekanski suggested that excess waste from SLS could be recovered and converted into filaments via FFF[53]. In this way, it is possible to produce filaments with better strength than existing products, reduce waste from SLS and allow materials reuse without defects and polydispersity limitation.

3.5 Vat Photopolymerization (VP)

Vat photopolymerization (VP) has been a difficult AM process for recycled materials due to the widespread use of thermoset resins. A wide range of polymer systems, including aromatic polyimides, polymers, and PEEK, have been added to the traditional VP, which was based on the processing of straightforward acrylate or epoxy monomers [54]. Addressing end-of-life long-term viability such as self-healing, recycling, or depolymerization as a means of reusing thermoset monomer, is the focus of VP's current materials growth efforts.

For thermosetting materials, Zhang et al. (2018) reported 3D printable reprocessable thermoset (3DPRT) was created by incorporating zinc acetylacetonate hydrate as a material for transformation, which leads to the formation of dynamic covalent bonds and allows crosslinked network rearrangement and reprocessing at high temperatures and cold as illustrated [55].Subsequently, Rossegger et al. Application of the dynamic covalent bond concept in the development of acrylate-based vitrimers for DLP using organophosphates as transesterification catalysts[56]. Similar to this, Zhao et al. (2021) created epoxy anhydride resin utilising diglycidyl ether of bisphenol A (DGEBA), which is regenerable with ethylene glycol at temperatures lower than 200°C [57]. Dimethylformamide (DMF), 1,2,4-trichlorobenzene (TCB), dichloromethane toluene, tetrahydrofuran (THF), and heptane are just a few of the solvents that DGEBA polymers are resistant to after curing, but they are soluble in ethylene glycol to generate separated epoxy polymers, which can be used to create new epoxy resins with better durability and chemical resistance.Urethane glass resin can be employed in new products either pulverised or decomposed in liquid and still preserves the same Tg and modulus as the raw material, said Hao et al. (2020), who generated a cross-linked epoxy glass mesh with quick dynamic transformation and a Tg of 135°C and a tensile strength of 94 MPa [58].

To advance the level of recycling materials for high-performance applications, Hernandez et al. (2022) demonstrated ability to recycle polymers for 3D printing using thioester meshes. 3D-printed thioester-based composites can degrade to recover more than 90% of the composite material, and the loss test is based on the analytical model for thiol-thioester exchange [59]. The recyclability of components makes the product suitable for long-term use and high performance.

A method for recycling VP thermosetting resins developed by Poelma et al. (2022). It uses reactive prepolymers that can be used after 3D printing and reused in materials to print new products [60]. He developed a method for making part of the thermoset web by extracting the reactive prepolymer into solvent, removing the solvent, and collecting the prepolymer as a new resin for printing prepolymer fillers but can be used to produce up to 90% new resin [61].

Large thermoplastic reuse and restoration materials is an important step in the chemical industry along high performance materials. AM Reducing raw materials should reduce the environmental impact of obtaining raw materials. However, the high viscosity of degradable thermoset photopolymers often hinders their application in VP techniques. When using lift and retraction mechanisms (SLA and DLP) or printing from thin die cavities with CLIP, the monomer resin's viscosity must be low enough to operate properly both during printing and during the lifting step. The current viscous limit is around 5 Pa [62]. While reactive diluents and other factors can be used to reduce the viscosity of the material to improve printing, these diluents will reduce the final electronic properties of the printed polymer. Recently, success has been achieved in improving the viscosity limit of vessel photopolymerization by injecting resin to reduce the time and volume of resin reflow.

Among bio-based polymers, proteins such as alginates, starches, oils and silk fibroin have been used to create materials with high biocompatibility but lacking strength and thermomechanical stability [63, 64].As a cellulose derivative, cellulose diacetate/acetate has been successfully used in fibres, films and coatings due to its excellent biocompatibility and biodegradability. In addition, cellulose diacetate has thermoplasticity after plastic is added and can be made into many types of plastics by making it thermoplastic. Because of its good transparency, selective permeability and high hardness, cellulose diacetate is widely used in many fields. Because of the strong interaction in cellulose diacetate, the molecular chain in cellulose diacetate is difficult to move, resulting in a higher glass transition temperature (Tg). However, high Tg of cellulose diacetate results in poor performance. Additionally, cellulose diacetate products generally have lower mechanical properties. Considering the weak thermoplasticity and low strength of cellulose diacetate there is need for modification of cellulose diacetate.

While biomaterials are not always suitable for high performance applications, they are promising in solving the problems associated with bioderived AM materials, such as fewer problems, less energy, and safety. When silk fibroin was added to poly(ethylene glycol)-tetra acrylate resin for DLP, for example, Shin et al. (2018) found that the solubility was improved [65]. In addition, Guit et al. developed a library of natural methacrylates that with personal hardness and toughness for use in photopolymer resin for 3D printing using epoxidized soybean oil [66]. Many other developments in bio-based, sustainable photopolymers for various 3D printing applications, including high-performance applications and others, have been reviewed recently[67].

4. FORTHCOMING PROSPECTIVES

A broad objective, sustainable in production and beyond covers a variety of areas, from materials to usage of energy and management. Some situations, sustainability may be a trade-off as research continues. For example, a thermoset may appear that can degrade and be renewable, but it will be based on synthetic materials that are not useful. Likewise, bio-based materials can be useful, but their processing will require a lot of effort.

Therefore, it is difficult to identify a single measure to measure the environmental impact of all developments in AM. Kellen et al. (2017). It describes many environmental aspects of AM and limited information about AM compared to commercial products [68]. Here we offer additional thoughts on additive manufacturing and how it affects the environment and people beyond material production.

4.1. Waste production in AM processes

Waste savings during Additive Manufacturing and technology costs relative to the standard used.AM's popular promise to decrease waste from manufacturing includes meshing and topology optimization to reduce the weight of the product. Such meshes cannot be produced by conventional manufacturing methods such as injection moulding or extrusion. In addition to the need for fewer materials to build itself, the weight of the reduction reduces fuel consumption in large vehicles such as airplanes and cars [69]. However, there are elements of additive manufacturing that are waste-free and require further technological development to reduce the overall footprint. For example, liquid waste resin from photopolymerization in barrels is considered a hazardous material and must be properly stored and disposed of [70].

4.1 Methodology to digital manufacturing

Additive manufacturing, like digital manufacturing, offers an approach to sustainable development beyond the material. Digital manufacturing is a combination of computer and the use of CAD models to enable the representation and analysis of products and processes prior to the start production [71]. Additionally, it enables tracking and evaluation of items for more thorough assessment. This talent will provide time for data to be collected and published in development tools, making it easier to translate cloud software updates to partners. People can also take advantage of the digital manufacturing process created to help create a future where every product will be uniquely stamped in the cloud with a unique, readable QR code.

For highly functional polymers that need to be stored for depolymerization and recycling for recycling, product tracking methods can provide good visibility into how well the product is doing. This information is important for laying the foundations for new business models and practices.For example, better tracking of equipment and product performance or failure can improve product returns, so only products made on defective products need to be returned. Also, such information can be useful for those who manage to rely on the manufacturing process based on the suitability and immediate performance of certain products. This test can be traced throughout the life of the product.

4.2 Opportunities for digital manufacturing

Digital manufacturing gives AM the key to continue to go beyond Rapid prototyping for on-demand product delivery, regional manufacturing flexibility, and access to previously unattainable products. The use of AM in digital manufacturing enables the manufacturing of spare parts on demand, eliminating the need for additional spare parts that must be kept in stock and, thus, the need for ventilated storage. Additionally, access to product samples and rapid production of products mean AM can bring more products back to the local community and reduce one of the biggest sources of air and water pollution by avoiding shipments to foreign countries.The move to local digital additive manufacturing has implications beyond the environmental impact: additive manufacturing can bring assets back into the system. According to UPS, more than 3% of the world's GDP is found in UPS trucks or trucks every day [72]. This gigantic trade can only be put back into circulation by reducing the amount of goods that must be transported [73].

In addition, manufacturers that frequently use additional equipment can quickly change lines as needed to meet global demand. For example, a local shoe manufacturer could easily switch from sneaker production to production of personal protective equipment (PPE) for first responders by importing 3D models into AM.This change happens almost instantaneously without the need for any factory restructuring and paves the way for the factory's jobs to change.

4.3 AM sustainability

Ecological efficiency is a phrase that refers to economy and business management, both of which can be achieved by improving equipment, reducing the amount of chemical product and enabling recycling [74]. Overall, improving equipment (and recycling) will lead to additional savings for the company (especially in the use of high-value products such as high-end products), in the form of reduced equipment, reduced liability, and legal and improved communications with all interested parties. Although investment in the purchase and development of fixed equipment will be required first, the financial and economic savings will benefit the public and private sectors in the long run. This can be seen, for instance, in the omission of toxic tin catalysts from polyurethane-based systems and the elimination of bisphenol A, a hormone disruptor, from epoxy resin systems [75].

The belief that the future will arrive is backed by the combination of superior corporate, academic, and ecological performance by investing in the region, not at the expense of developing it. For example, in 3M's 3P program, aggressive investment in process reengineering and data R&D approaches has resulted in more than 2.6 billion pounds of pollution prevention and $1 billion in savings over a 30-year period [76]. The additive manufacturing space can learn from 3M's success and use eco-efficiency to drive early development rather than rethinking and recreating past processes. Eco-saving needs can provide opportunities for ecological and economic efficiency. Table 1 shows the different methods for manufacturing of AM and the sources.

Table 1. Different methods for manufacturing of AM and their sources

Methodology for Artificial Manufacturing	**Source**	**Material**	**Methodology of degradation or reprocessing**	**References**
Material extrusion	Imitation	Polylactic Acid (PLA)	Diels-Alder networks Thermoplastics	[36]
	Waste from Consumers	Polypropylene (PP) Poly tetra ethylene (PET) Polystyrene (PS)	Thermoplastics	[77]
	Reprocessed powders	Polycarbonate (PC)	Thermoplastics	[78]
	Wooden	Composites of Polylactic Acid	Thermoplastics	[79]
	Wooden	Wood	Biodegradable/Recyclable	[80]
	Cellulosic polymers, Imitation	Composites, Acrylates	N/A	[81]
	Lignin	Composites of nylon, ABS	N/A	[82]
	Imitation	Polyaryletherketone (PEEK)	Thermoplastics	[83]
	Wastes from industries	Geopolymers	Reusable	[44]
	Imitation	Thermoplastics with semi crystallinity	Diels-Alder networks	[45]
	Imitation	Composites of Elastomers	Diels-Alder networks	[84]
	Imitation	Epoxies	Vitrimer	N/A
Material/binder jetting	N/A	N/A	N/A	N/A
Polymer powder	Imitation	Polyamides,	Thermoplastics	[85]
Bed fusion		Polystyrene, Polycarbonates, Polyaryletherketone	Thermosets	[55]
Vat	Imitation	Acrylate's	Thermosets	[55]

photopolymerization				
	Imitation	Acrylate's	Thermosets	[56]
	Imitation	DGEBA	Thermosets	[57]
	Imitation	Epoxies	Thermosets	[58]
	Imitation	Polythiourethane	Thermosets	[86]
	Imitation	Composites of Thioesters	Thiol-thioester exchanges	[59]
	Imitation	Polyurethanes, Acrylate's,	Biodegradable crosslinks	[60]
	Lignin	Acrylate's	Solvent free fabrication	[87]
	Lignin	Vinyl esters	Solvent free fabrication	[88]
	Oils from Soyabean's	Epoxies	Naturally available materials	[66]

5. CONCLUSION

A particular area for manufacturing process disruption is additive manufacturing. Engineers and researchers, have an agreement to protect waste products from AM polymers for years. Although additive manufacturing has the potential to reduce waste and CO_2Though having lower emissions than traditional manufacturing, it cannot totally eliminate waste. High-performance polymers can be designed to be more versatile for use in all types of additive production (material the extrusion process boat a process called photo powder bed fusion, etc.) stable while still meeting the requirements.

The sustainability of a polymer depends on how the raw material is used or how the final product is degraded and reused. Recycled decomposition comes in two types: passive decomposition and induced decomposition. For high performance users, annealing is the best way to provide high hardness, strength, non-functional or thermal and chemical resistance to polymers with environmental requirements. High-performance polymers may go to waste and lower the cost of raw materials needed for more by being totally recyclable under extremely specific yet favourable circumstances. The best technique for recycling thermoset polymers may use chemical breakdown rather than thermal deterioration because it takes less energy.

Advanced polymers that, under extremely focused but favourable conditions, can be totally recycled can both contribute to waste and lower the cost of raw materials required for more production. Since it needs less energy than the use of heat, chemical destruction of polymers that are thermoset for recycling may be the optimum option for effective materials.

REFERENCES

References

1. Kearney 3D Printing, https://www.kearney.com/operationsperformance transformation/article/?/a/3d-printing-disrupting-the-12-trillion-manufacturing-sector, (accessedApril 10, 2022).
2. I. Campbell, D. Bourell and I. Gibson, Rapid Prototyp. J., 2012, 18, 255–258.
3. M. Gebler, A. J. M. SchootUiterkamp and C. Visser, Energy Policy, 2014, 74, 158–167.
4. H. Kodama, Rev. Sci. Instrum., 1981, 52, 1770–1773.
5. J. D. Cawley, Curr. Opin. Solid State Mater. Sci., 1999, 4, 483–489.
6. P. Colombo, G. Mera, R. Riedel and G. D. Sorarù, J. Am. Ceram. Soc., 2010, 93, 1805–1837.
7. W. E. King, A. T. Anderson, R. M. Ferencz, N. E. Hodge, C. Kamath, S. A. Khairallah and A. M. Rubenchik, Appl. Phys. Rev., 2015, 2, 041304.

8. G. N. Levy, R. Schindel and J. P. Kruth, CIRP Ann. Manuf. Technol., 2003, 52, 589–609.
9. S. Hong, D. Sycks, H. F. Chan, S. Lin, G. P. Lopez, F. Guilak, K. W. Leong and X. Zhao, Adv. Mater., 2015, 27, 4035–4040.
10. C. B. Highley, C. B. Rodell and J. A. Burdick, Adv. Mater., 2015, 27, 5075–5079.
11. O. Ivanova, C. Williams and T. Campbell, Rapid Prototyp. J., 2013, 19, 353–364.
12. W. Liu, Y. Li, J. Liu, X. Niu, Y. Wang and D. Li, J. Nanomater., 2013, 2013, e681050.
13. A. J. Capel, R. P. Rimington, M. P. Lewis and S. D. R. Christie, Nat. Rev. Chem., 2018, 2, 422–436.
14. W. Jamróz, J. Szafraniec, M. Kurek and R. Jachowicz, Pharm. Res., 2018, 35, 176.
15. S. V. Murphy and A. Atala, Nat. Biotechnol., 2014, 32, 773–785.
16. K. Dubbin, Y. Hori, K. K. Lewis and S. C. Heilshorn, Adv. Healthcare Mater., 2016, 5, 2488–2492.
17. D. Bourell, J. P. Kruth, M. Leu, G. Levy, D. Rosen, A. M. Beese and A. Clare, CIRP Ann., 2017, 66, 659–681.
18. C. A. Chatham, M. J. Bortner, B. N. Johnson, T. E. Long and C. B. Williams, Predicting Mechanical Property Plateau in Laser Polymer Powder Bed Fusion Additive Manufacturing via the Critical Coalescence Ratio, Social Science Research Network, Rochester, NY, 2021.
19. J. Huang, Q. Qin and J. Wang, Processes, 2020, 8, 1138.
20. Z. Zhao, X. Tian and X. Song, J. Mater. Chem. C, 2020, 8, 13896–13917. 43 J. R. Tumbleston, D. Shirvanyants, N. Ermoshkin, R. Janusziewicz, A. R. Johnson, D. Kelly, K. Chen, R. Pinschmidt, J. P. Rolland, A. Ermoshkin, E. T. Samulski and J. M. DeSimone, Science, 2015, 347, 1349–1352.
21. R. Janusziewicz, J. R. Tumbleston, A. L. Quintanilla, S. J. Mecham and J. M. DeSimone, Proc. Natl. Acad. Sci. U. S. A., 2016, 113, 11703–11708.
22. A. R. Johnson, C. L. Caudill, J. R. Tumbleston, C. J. Bloomquist, K. A. Moga, A. Ermoshkin, D. Shirvanyants, S. J. Mecham, J. C. Luft and J. M. DeSimone, PLoS One, 2016, 11, e0162518.
23. H. O. T. Ware and C. Sun, J. Micro Nano-Manuf., 2019, 7(3), 031001.
24. A. A. Bhanvadia, R. T. Farley, Y. Noh and T. Nishida, Commun. Mater., 2021, 2, 1–7.
25. J. Bachmann, E. Gleis, G. Fruhmann, J. Riedelbauch, S. Schmölzer and O. Hinrichsen, Addit. Manuf., 2021, 37, 101677.
26. C. L. Caudill, J. L. Perry, S. Tian, J. C. Luft and J. M. DeSimone, J. Controlled Release, 2018, 284, 122–132.
27. C. Caudill, J. L. Perry, K. Iliadis, A. T. Tessema, B. J. Lee, B. S. Mecham, S. Tian and J. M. DeSimone, Proc. Natl. Acad. Sci. U. S. A., 2021, 118, e2102595118.
28. M. Geissdoerfer, P. Savaget, N. M. P. Bocken and E. J. Hultink, J. Cleaner Prod., 2017, 143, 757–768.
29. K. Boulding, Res. Pap. – Resour. Future, 1966, 1–14.
30. A. V. Kneese, Popul. Dev. Rev., 1988, 14, 281–309. 54 N. D. Miller and D. F. Williams, Biomaterials, 1984, 5, 365–368.
31. M. J. Krause and T. G. Townsend, Environ. Sci. Technol. Lett., 2016, 3, 166–169.
32. E. M. Maines, M. K. Porwal, C. J. Ellison and T. M. Reineke, Green Chem., 2021, 23, 6863–6897.
33. K. J. Jem and B. Tan, Adv. Ind. Eng. Polym. Res., 2020, 3, 60–70.
34. T. Kitamura and A. Matsumoto, Macromolecules, 2007, 40, 509–517.
35. J. Korpela, A. Kokkari, H. Korhonen, M. Malin, T. Närhi and J. Seppälä, J. Biomed. Mater. Res., Part B, 2013, 101, 610–619.
36. G. A. Appuhamillage, J. C. Reagan, S. Khorsandi, J. R. Davidson, W. Voit and R. A. Smaldone, Polym. Chem., 2017, 8, 2087–2092.

37. K. M. Rahman, T. Letcher and R. Reese, in Volume 2A: Advanced Manufacturing, American Society of Mechanical Engineers, Houston, Texas, USA, 2015, p. V02AT02A009.
38. US Patent for Reversible thermosets for additive manufacturing Patent (Patent # 11,135,744 issued October 5, 2021) - Justia Patents Search, https://patents.justia.com/patent/ 11135744, (accessed December 7, 2021).
39. S. Saleh Alghamdi, S. John, N. Roy Choudhury and N. K. Dutta, Polymers, 2021, 13, 753.
40. J. Davidovits, J. Therm. Anal., 1991, 37, 1633–1656.
41. A. Akbarnezhad, M. Huan, S. Mesgari and A. Castel, Constr. Build. Mater., 2015, 101, 152–158.
42. M. Despeisse and S. Ford, in Advances in Production Management Systems: Innovative Production Management Towards Sustainable Growth, ed. S. Umeda, M. Nakano, H. Mizuyama, H. Hibino, D. Kiritsis and G. von Cieminski, Springer International Publishing, Cham, 2015, pp. 129–136.
43. K. Mikula, D. Skrzypczak, G. Izydorczyk, J. Warchoł, K. Moustakas, K. Chojnacka and A. Witek-Krowiak, Environ. Sci. Pollut. Res., 2021, 28, 12321–12333.
44. K. Yang, J. C. Grant, P. Lamey, A. Joshi-Imre, B. R. Lund, R. A. Smaldone and W. Voit, Adv. Funct. Mater., 2017, 27, 1700318.
45. Y. Guo, S. Chen, L. Sun, L. Yang, L. Zhang, J. Lou and Z. You, Adv. Funct. Mater., 2021, 31, 2009799.
46. Q. Shi, K. Yu, X. Kuang, X. Mu, C. K. Dunn, M. L. Dunn, T. Wang and H. J. Qi, Mater. Horiz., 2017, 4, 598–607.
47. O. Davydovich, J. E. Paul, J. D. Feist, J. E. Aw, F. J. Balta Bonner, J. J. Lessard, S. Tawfick, Y. Xia, N. R. Sottos and J. S. Moore, Chem. Mater., 2022, 34, 8790–8797.
48. O. Gülcan, K. Günaydın and A. Tamer, Polymers, 2021, 13, 2829.
49. I. Gibson, D. Rosen, B. Stucker and M. Khorasani, in Additive Manufacturing Technologies, ed. I. Gibson, D. Rosen, B. Stucker and M. Khorasani, Springer International Publishing, Cham, 2021, pp. 203–235.
50. C. A. Chatham, T. E. Long and C. B. Williams, Prog. Polym. Sci., 2019, 93, 68–95.
51. Y. Wang, Z. Xu, D. Wu and J. Bai, Materials, 2020, 13, 2406.
52. R. Goodridge and S. Ziegelmeier, in Laser Additive Manufacturing, ed. M. Brandt, Woodhead Publishing, 2017, pp. 181–204.
53. S. Kumar and A. Czekanski, Mater. Today Commun., 2018, 15, 109–113.
54. I. Gibson, D. Rosen, B. Stucker and M. Khorasani, Additive Manufacturing Technologies, Springer International Publishing, Cham, 2021.
55. B. Zhang, K. Kowsari, A. Serjouei, M. L. Dunn and Q. Ge, Nat. Commun., 2018, 9, 1831.
56. E. Rossegger, R. Höller, D. Reisinger, M. Fleisch, J. Strasser, V. Wieser, T. Griesser and S. Schlögl, Polymer, 2021, 221, 123631.
57. W. Zhao, L. An and S. Wang, Polymers, 2021, 13, 296.
58. C. Hao, T. Liu, S. Zhang, W. Liu, Y. Shan and J. Zhang, Macromolecules, 2020, 53, 3110–3118.
59. J. J. Hernandez, A. L. Dobson, B. J. Carberry, A. S. Kuenstler, P. K. Shah, K. S. Anseth, T. J. White and C. N. Bowman, Macromolecules, 2022, 55, 1376–1385.
60. R. H. N. J. Poelma and R. H. N. Curvers, World Intellectual Property Organization, WO2021183741A1, 2021.
61. J. Poelma, M. S. Zhang, X. Gu, J. P. Rolland and J. M. DeSimone, Carbon Inc., United States, US011299576B2, 2022.
62. J. Herzberger, J. M. Sirrine, C. B. Williams and T. E. Long, Prog. Polym. Sci., 2019, 97, 101144.
63. J. Jia, D. J. Richards, S. Pollard, Y. Tan, J. Rodriguez, R. P. Visconti, T. C. Trusk, M. J. Yost, H. Yao, R. R. Markwald and Y. Mei, Acta Biomater., 2014, 10, 4323–4331.

64. X. Mu, V. Fitzpatrick and D. L. Kaplan, Adv. Healthcare Mater., 2020, 9, 1901552.
65. S. Shin, H. Kwak and J. Hyun, ACS Appl. Mater. Interfaces, 2018, 10, 23573–23582.
66. J. Guit, M. B. L. Tavares, J. Hul, C. Ye, K. Loos, J. Jager, R. Folkersma and V. S. D. Voet, ACS Appl. Polym. Mater., 2020, 2, 949–957.
67. V. S. D. Voet, J. Guit and K. Loos, Macromol. Rapid Commun., 2021, 42(3), 2000475.
68. K. Kellens, M. Baumers, T. G. Gutowski, W. Flanagan,R. Lifset and J. R. Duflou, J. Ind. Ecol., 2017, 21, S49–S68.
69. S. K. Moon, Y. E. Tan, J. Hwang and Y.-J. Yoon,Int. J. Precis. Eng. Manuf. – Green Technol., 2014, 1, 223–228.
70. S. Shanmugam, A. Naik, T. Sujan and S. Desai, INCOSEInt. Symp., 2019, 29, 394–407.
71. D. Mourtzis, N. Papakostas, D. Mavrikios, S. Makris and K. Alexopoulos, Int. J. Comput. Integr. Manuf., 2015, 28,3–24.
72. O. US EPA, Reducing Air Pollution from International Transportation, https://www.epa.gov/international-cooperation/reducing-air-pollution-international-transportation, (accessedDecember 6, 2021).
73. UPS Supports the Administration to Serve the Economic and Healthcare Interests of the Nation | About UPS, https://about.ups.com/us/en/newsroom/press-releases/customer-first/ups-supports-the-administration-to-serve-the-economic-and-healthcare-interests-of-the-nation, (accessedDecember 7, 2021).
74. L. D. DeSimone and F. Popoff, Eco-efficiency: The BusinessLink to Sustainable Development, MIT Press, 2000.
75. M. G. Royston, Pollution Prevention Pays, Elsevier, 2013.
76. O. US EPA, 3M – Lean Six Sigma and Sustainability,https://www.epa.gov/sustainability/3m-lean-six-sigma-andsustainability, (accessed September 7, 2022).
77. 7 N. E. Zander, M. Gillan, Z. Burckhard and F. Gardea,Addit. Manuf., 2019, 25, 122–130
78. M. J. Reich, A. L. Woern, N. G. Tanikella and J. M. Pearce,Materials, 2019, 12, 1642.
79. A. Le Duigou, M. Castro, R. Bevan and N. Martin, Mater.Des., 2016, 96, 106–114
80. D. Kam, M. Layani, S. BarkaiMinerbi, D. Orbaum, S. A. BenHarush, O. Shoseyov and S. Magdassi, Adv.Mater. Technol., 2019, 4, 1900158.
81. G. Siqueira, D. Kokkinis, R. Libanori, M. K. Hausmann, A. S. Gladman, A. Neels, P. Tingaut, T. Zimmermann, J. A. Lewis and A. R. Studart, Adv. Funct. Mater., 2017, 27,1604619.
82. 5 N. A. Nguyen, S. H. Barnes, C. C. Bowland, K. M. Meek, K. C. Littrell, J. K. Keum and A. K. Naskar, Sci. Adv., 2018,4(12), 4967
83. B. Hu, X. Duan, Z. Xing, Z. Xu, C. Du, H. Zhou, R. Chenand B. Shan, Mech. Mater., 2019, 137, 103139.
84. Q. Shi, K. Yu, X. Kuang, X. Mu, C. K. Dunn, M. L. Dunn,T. Wang and H. J. Qi, Mater. Horiz., 2017, 4, 598–607
85. W. Stansbury and M. J. Idacavage, Dent. Mater., 2016,32, 54–64
86. Cui, L. An, Z. Zhang, M. Ji, K. Chen, Y. Yang, Q. Su,F. Wang, Y. Cheng and Y. Zhang, Adv. Funct. Mater., 2022,32, 2203720.
87. R. Ding, Y. Du, R. B. Goncalves, L. F. Francis and T. M. Reineke, Polym. Chem., 2019, 10, 1067–1077.
88. A. W. Bassett, A. E. Honnig, C. M. Breyta, I. C. Dunn, J. J. La Scala and J. F. Stanzione, ACS Sustainable Chem.Eng., 2020, 8, 5626–5635.