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Manufacturing methods used to produce certain biocomposite materials – a mini-review

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Abstract. In recent years, interest in biocomposite materials has grown significantly, due to the potential to replace conventional materials. The increasing use of biocomposite materials in various fields (aerospace, automotive, maritime transport, sports equipment, energy, construction, medicine), is due to their characteristics, superior to those of conventional materials, the reduction of energy consumption required for their production, the increased resistance to corrosion, tear resistance, wear resistance, high temperature, strength, low density, controllable thermal conductivity, good deformability, exceptional dimensional stability, low thermal expansion, impact resistance and many other characteristics that, unlike classical materials, are convenient. This study reviews the manufacturing methods used to produce certain biocomposite materials.

Keywords: biocomposite, manufacturing methods, review

INTRODUCTION

Biocomposites consist of two constituents: reinforcement and matrix [1]. The matrix has a dual role: to keep the fibers/particles used as the reinforcement system compact and to transfer the resulting stresses in case of external stresses to the reinforcement fibers. The matrix can be based on polymer, metal or ceramic.

The properties of such a composite material will depend in this case not only on the intrinsic characteristics of the two components, but also on the spatial arrangement of the fibers/particles within the matrix and the degree of matrix-fiber adhesion.

In recent years, much attention has been paid to the need to reduce global warming, environmental damage and pollution. Biocomposites are degradable, renewable, non-abrasive and non-toxic, without emissions of gases or poisonous substances [2]. Microbes degrade biomaterials into organic matter by decomposition, along with the release of minerals, water, and CO2 [3,4]. Industries are encouraged to use environmentally friendly materials to have a better impact on the environment [5]. Biocomposites are promising materials to decrease energy demand [6] and reducing carbon footprint [7,8].

There is also a growing trend to use biofibers as fillers and/or reinforcements in plastic composites. Their flexibility during processing, high specific stiffness and low cost make biocomposites attractive to manufacturers [9].

In the automotive industry, biocomposites are used to make door panels and inserts, rear trunk lids, side rims, tool box area, seat backs, dashboards, and parcel shelves [10, 11].

In the aeronautical industry, biocomposites are used for the manufacture of various critical parts, which need a thermally stable and high-strength material.

Traditional biocomposites are mainly manufactured using existing techniques for processing plastics or synthetic composite materials.

In this article, the different processing techniques of biomaterials and their applicability to biocomposite structures are presented.

The factors that influence the choice of manufacturing techniques for obtaining certain biocomposites are [12]:

– material processing temperature;

– the desired rate of control over the distribution of different materials, both proportional and geometric (when designing parts);

– the required general porosity;

– size of construction fibers;

– geometric randomness or required periodicity.

MANUFACTURING METHODS OF BIOCOMPOSITE

A. Conventional Processing Techniques

1. Extrusion

Extrusion is the process by which a solid plastic (beads or pallets) is continuously fed into a heated chamber and transported by a feed screw inside [13].

Single-screw or twin-screw extruders are used, and the screws are rotated clockwise or counterclockwise, depending on the end products.

Extrusion is a hot melt technique used for the continuous production of biocomposites.

In the case of biocomposites, thermoplastic resin beads or pallets are mixed together with 30 to 40% of short/long natural fibers, compressed, melted and forced out through a die.

As the solid resin is transported, it is compressed, melted and forced out of the chamber through a die. The extruded product is cooled and cut to the desired dimensions. After the cooling process, the molten part results in a continuous profile.

The final properties of biocomposites obtained by extrusion depend on two factors [14]:

1). *Type of components used*

The components used must be in a physical form suitable for thermo-mechanical processing. During extrusion, if the temperature is high and the shearing forces are high, degradation of the components with the emission of volatile substances can occur.

2). *Processing conditions* during extrusion (cylinder temperature, screw speed, shear forces, residence time distribution, etc.), which affect the homogeneity of the produced biocomposites.

2. Injection molding

Injection molding is a mass production process that can produce large quantities of solid plastic parts repeatedly at fast cycle times. High production is beneficial to the company's labor costs. Plastic products are produced in complex and intricate details, an advantage of this process that would otherwise be too expensive or difficult to achieve. Defects in the finished product can also be easily fixed, a small amount of material is wasted, adding the cost-saving benefits to the whole process.

Injection molding presents numerous benefits for the environment: reduced waste, ease of recycling and durability of the product.

Like the extrusion process, injection molding relies on the plasticity of the molten polymer. In injection molding, a certain amount of material is metered in front of the screw, which then forces the materials into the cavity of a closed mold [12].

In injection molding, the feed matrix consisting of the polymer matrix and the reinforcement is heated to plasticity, in a cylindrical barrel, at a controlled temperature. Injection molding is used to make composite products, where complex, large-volume shapes are required. The advantages of using the process have an excellent dimensional tolerance and short cycle times, along with few post-processing operations [13].

Injection molding equipment is expensive and the process has limited top members or short fiber reinforcement [15].

3. Filament winding

Filament winding is a conventional manufacturing technique capable of forming composite structures by winding filaments under tension over a rotating mandrel. It is an automatic method used to form voids in composite structures. To deposit the fibers in the desired pattern, the mandrel rotates while a carriage moves horizontally. When the mandrel is completely covered to the desired thickness, it can be removed and thus the final hollow product is formed [16]. Some mandrels are collapsible to facilitate the removal of parts. The overall size and shape of the finished part is determined by the shape of the mandrel and the thickness of the laminate.

The mechanical properties of composite parts: strength, stiffness and weight are determined by the wrap angles. Parts obtained by this technique generally have good weight resistance properties.

The advantages of the technique: very fast method, the possibility of adopting automation and robotization procedures, perfectly controlled fiber deposition, the resin content can be controlled, the cost of the fibers is minimized, the structural properties of the laminates can be very good, optimal mechanical properties, low porosity, high rigidity, superior vibration damping, very low thermal expansion.

Disadvantages of the technique: the fiber cannot easily be placed exactly along the length of a component, for large components the mandrel costs are high, the outer surface of the component is not molded, for convex shaped parts the process is limited [17].

4. Compression

Compression molding is a conventional process in which preheated molding material is introduced into an open, heated mold cavity. The mold is closed with a superior force or plug element. Pressure is applied to force the material into contact with all areas of the mold, while heat and pressure are maintained until the casting material has hardened [12].

When the cast product is removed, it contains excess material, which was extruded while being heated and compressed in the mold. This is removed to maintain the exact measurement of the manufactured product.

A particularly important when setting the process parameters is the composition of the material. In addition to part shape and thickness, material selection determines the required preheat temperature, molding temperature, molding pressure, pressure hold time, cooling rate, discharge pressure, discharge times, and blank support force.

The factors on which compression molding depends are: raw material, shape (mold), pressure applied, temperature and curing time.

The compression molding technique is one of the least expensive to mass produce products due to its cost effectiveness and efficiency. This method is very efficient, leaving little material.

The technique produces high-volume parts of varying lengths, thicknesses and complexities at a better cost per part than alternative manufacturing processes. They are dimensionally accurate, temperature resistant and with a good surface quality.

5. Autoclave molding

The method of autoclaving is very similar to vacuum packaging with a few changes. The heat and pressure required by the biocomposites during the curing stage is provided by the autoclave machine.

Pressure is necessary to achieve a sufficient level of fiber content and to reduce residual porosity in the composites. Parts processed in an autoclave are often vacuum packed to allow the pressure to work isostatic on the workpieces.

The autoclave is a closed vessel in which the simultaneous application of high pressure and temperature is feasible, to help uniform and efficient matrix distribution, as well as good fiber-matrix interfacial adhesion or bonding for a defined time interval [18].

There are two classes of autoclaves: steam pressurized ones produce parts that can withstand exposure to water, while circulating heated gas provides greater flexibility and control of the heating atmosphere.

Casting in an autoclave has the following advantages and disadvantages [18]:

✓ *Advantages*

- better adhesion between layers;
- good control of both fiber and resin;
- the degree of uniformity in the solidification of the components is high;
- supports a high-volume fraction of fibers in the composite component;
- a better bond of the interface with inserts and cores is often obtained.

✓ *Disadvantages*

- low production rate;

- restrictions on the size of the composite components, which depends on the size of the autoclave machine;
- involvement of qualified workforce;
- the expensive technique of processing composites.

The stages of the autoclave process are: preparation and stacking of layers, addition of dry material to absorb excess resin, removal of volatiles, application of vacuum bag and autoclave curing, post-oven polishing for ecological durability (oven post-cure for environmental durability), trimming and inspection.

Autoclaving is much more expensive than standard oven heating and is therefore generally used only when isostatic pressure must be applied to a part of relatively complex shape [12].

The cooling rate must be adapted so as to obtain a degree of crystallinity and to avoid microcracking [19].

B. Solution-based techniques

Solvent casting

Solvent casting is a simple method to obtain simple shapes, which is performed at room temperature [20].

In this method, water-soluble polymers are dissolved in water. The drug along with other excipients is dissolved in suitable solvent, then both solutions are mixed and shaken and then transferred into a Petri dish and dried. Glass, plastic or Teflon plates are used. Drying is done in an oven or a convection chamber, to remove solvents. The solvents used for the preparation of the solution or suspension must be selected from the ICH class 3 - list of solvents [21-23]. Dry, solvent-cast films may contain traces of residual solvents, which could present compliance issues.

If any of the solvents used are flammable (ethanol), special safety equipment and procedures must be used to prevent fires and environmental hazards from the vaporized solvent [24].

Films obtained by solvent casting are prone to brittleness and have a low surface-to-volume ratio and low drug loading capacity compared to electrospun films [25-26].

The *advantages* of the method are: ease of manufacture, lack of specialized equipment and low processing temperatures. The technique also presents disadvantages: possible retention of the toxic solvent in the polymer, limited geometries and possible denaturation of natural proteins by the solvent [20].

C. Additive Manufacturing – AM

Biocomposites can be obtained through an innovative technique, which consists of numerically controlled devices, which are based on a computer, for the production of 3D structures. Using 3D printing, objects made of metal, plastic, ceramic, glass, sand or other materials are built up in layers until they reach their final shape. This technology is called AM (additive manufacturing), rapid prototyping (RP) or solid free fabrication (SFF). AM is a technique for manufacturing parts layer by layer from 3D CAD files [27-29].

Additive manufacturing (AM) technologies are used to produce customized and complex parts. They allow companies to improve product quality, reduce material waste, decrease energy intensity, reduce production costs and reduce time to market [30-32].

An important role in the solidification process is played by the base material, for which there are three main categories: polymers, metal alloys and ceramics. The ceramic is processed as a powder to obtain AM parts. During the process, the resin is used to bond the ceramic particles. A post-treatment (a burnishing operation) is necessary to solidify the binder and increase the part's density and mechanical properties [29, 33].

AM technologies that use metal alloys are based on three principles to obtain the materials [29, 33-34]:

- ✓ The first consists in sintering or selectively melting the metal powder and applying the melt to form the product - the method Selective Laser Sintering (SLS);
- ✓ The second method is similar to ceramics and starts from powders. They are bound together by using different binders;
- ✓ The third technology is the selective melting process – the selective laser melting method Selective Laser Melting (SLM).

Additive manufacturing (AM) has the following advantages and disadvantages:

Advantages of additive manufacturing

- the piece can be printed directly from the 3D model without the need for a drawing;
- can print complex 3D geometries, without any tools;
- production tools can be printed;
- during the printing process different materials can be mixed to create a unique alloy;
- prototypes can be made faster;
- waste reduction compared to processing.

Disadvantages of additive manufacturing

- high production costs due to the cost of the equipment;
- the construction process is slow and expensive;
- poor mechanical properties, require different post-processing;
- the surface finish, texture and resistance of the parts are weaker compared to the manufacturing processes: pressure casting, investment casting or CNC machining.

The development of additive manufacturing (AM) technology has made numerous advances in biomedical and tissue engineering applications. AM has good intelligent manufacturing capability. This technique can build parts of three-dimensional (3D) complex geometries, of biomedical implants, which present controlled process parameters and use innovative materials, especially functional biocomposites [35].

In aerospace applications, these technologies can be used to create new porous or hollow components with internal geometries that maintain strength and reduce weight.

CONCLUSIONS

The methods presented in this work offer a lot of innovation possibilities during the manufacturing for biocomposites.

A. Conventional processing techniques

- *Extrusion and injection* - the curing phase of the composite contains short fibers and/or particles;
- *Filament winding* - creates hollow composite structures such as pipes, pressure vessels and yacht masts;
- *Compression* - the molding material, generally preheated, is first placed in an open, molded cavity of the mold;
- *Autoclaving* – heat and pressure are applied to the workpiece placed inside the autoclave.

B. Solution-based techniques

- *Solvent casting* - simple method for creating uncomplicated shapes, such as flat sheets, which are executed at room temperature.

C. Additive Manufacturing - AM

- *Additive manufacturing technology* - improved (automated) method for manufacturing a physical model or prototype from a 3D CAD file. Always start from a 3D CAD file, preferably a 3D solid file.

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