Functional lightweight materials: outlook, future trends and challenges

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Abstract: The growing demand for weight-saving engineering applications has led to the progress of lightweight composites with functional properties for an increasing number of applications. Lightweight materials with functional properties can be developed using a wide range of host matrices and reinforcement material. These large variety of possible combinations allow the development of new functional materials, structures and devices and that represent the present and the future of different engineering areas. Their novel properties combined with advanced manufacturing processes strongly increases the use of these materials in applications. This chapter presents some relevant challenges and an outlook on the future of this field.

Keywords: lightweight materials; challenges; future trends

14.1. Introduction

Lightweight functional materials are being increasingly demanded in areas ranging from sensors and actuators, to materials for structural and environmental applications, energy generation and storage or biomedicine, where both, functional response and processability in specific shapes or dimensions is essential to meet specific application demands.

Figure 1 shows representative applications and functionalities related to the area of multifunctional lightweight materials that result from the combination of polymers and specific fillers. Functionality may be attributed to one of the component and / or result from the combination of them. Thus, piezoelectric response can be either achieved by a piezoelectric polymer and/or piezoelectric ceramic filler. The piezoresistive character results from the combination of polymers with conductive filler, being maximized around the percolation threshold.

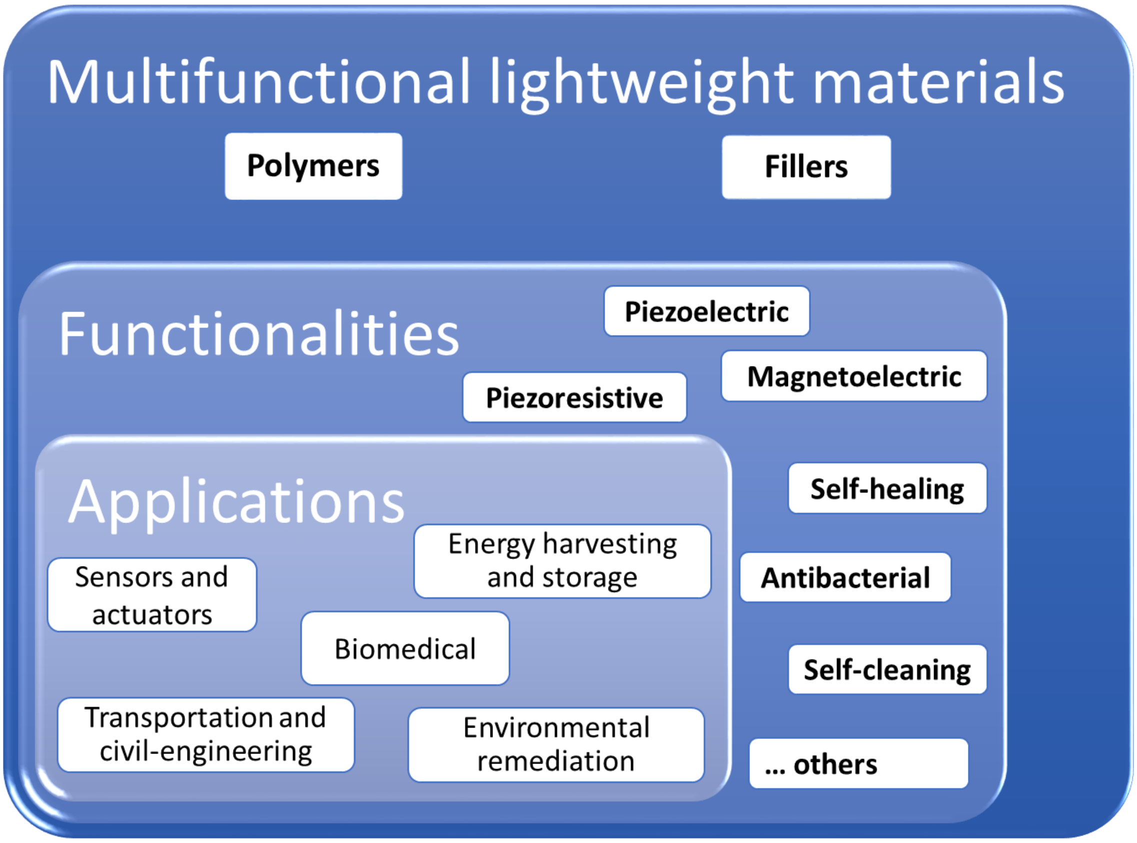

Figure 1 - Multifunctional lightweight materials: applications and functionalities

Further, advances in the area of additive manufacturing allow to implement those materials by printing technologies, allowing simple integration into applications as well as the development of new shapes and implementation in large areas, flexible and conformable surfaces [1, 2]. Thus, materials can be tailored for specific applications, with customized design both in two and three dimensions [3].

14.2. Outlook and Future Trends

The polymer-filler binominal has been essential in the implementation of a wide variety of lightweight multifunctional materials.

Functional intrinsic polymers and composites have been used with respect to piezoelectric polymer for sensing and energy harvesting or in the area of polymers reinforced with carbon black for antistatic casing goods in the industry. These smart materials have been processed with a large variety of processing methods, including solvent based and from the melt, tailoring them from thin or thick films, to porous membranes, or three dimensional objects [4].

Environmental considerations has fostered the search for novel and portable energy harvesting and storage systems, mainly for low-power devices [5]. Multifunctional materials have been also applied on batteries or capacitors, solar cells or mouldable electronics applications. Thermoelectric materials can generate energy from thermal gradients and thermochromic materials can works as sensor or energy-saving materials, insulating the indoor spaces changing the opacity of the window. Wearable thermoelectric generators are an auspicious energy source for a wide variety of applications.

Electrochromic materials are playing an increasing role with respect to energy-saving in modern cities, controlling the sunlight inside the buildings. Those materials allow light modulation for maintaining acceptable comfort conditions in the indoor environment. Novel electrochromic materials have been used as smart glass in other areas such as sunglasses, automobiles and military applications. Electrorheological materials allow controlled stress transfer and implementation in damping devices or tactile displays.

Another property that has been taken to advantage in polymer-based composites is their mechanical properties, such as the stretchability of elastomeric polymers. Materials with piezoresistive and conductive properties are used to develop sensor devices for structural health monitoring and biomechanical devices. Large deformation sensors with accurate performance manufactured by printing technologies are being implemented in areas ranging from automobiles, aircrafts or civil structures, to wearables and sport and biomedical devices.

Magnetic polymer composite materials with functional properties have become a requirement in distinct applications using permanent magnets for data-transmission, power generating and energy conversion in transformers or motors.

Shape memory alloys have been developed in the last decades from bulk materials to thinner films with excellent overall properties, such as large reversible strains and stress or shape recovery. Miniaturization of these materials allows new and exciting applications.

Magnetic field sensors implementation for non-contact location of moving objects and electronic guiding have been used in the last decades, but novel effects, such as magnetoelectric composites, can allow a next generation of magnetic sensor applications. Noise reduction in this kind of sensors is one of the most important technological achievements in the area.

Stimulus-sensitive smart gels are focus on biomedical applications. Biocompatible smart gels can react to a wide diversity of physical parameters such as temperature, pH, light, electric and magnetic field varying their swelling and macroscopic properties.

Functional antibacterial natural and biopolymers that can be reinforced with nanoparticles show excellent properties as high-efficient, cost-effective and environmental friendly bacteria-killing material applications, mainly in the areas of food spoilage of hospital-acquired infections. Food packing, shoes and textiles, contact lenses and gels are the main application in this field.

Ferroelectric polymers present huge advantages of these materials for applications, more specifically for sensors and energy harvesting devices. The piezoelectric coefficients of these polymers (mainly the PVDF-family) are lower when compared to crystalline materials but allow large area, flexible and tailor-made manufacturing..

14.3.Open Challenges

Sensors, actuators, energy harvesting and storage manufactured from host polymer materials have the advantages of low-cost combined with easy processing, compared to traditional materials. This field of application have an enormous potential in the scientific field with respect to filler and polymer properties developments, and in the engineering field, with easy and fast device integration.

Nevertheless, the progression margin of the overall properties of lightweight polymer composite materials is still quite large.

The progress in reinforcement fillers properties, dimensions and geometry, as well as compatibility of the polymer matrix will allow higher performance and tailored response for each specific application. Also, fillers functionalization will allow to improve the mechanical, chemical and electrical properties of the composites [6].

Further, it is still necessary to improve compatibility of materials with specific processing techniques, allowing to maintain proper filler dispersion and not damaging materials functional response or long-term stability due to specific processing conditions[7].

In particular, lightweight functional materials present important advantages for sensing/actuating and harvesting applications compared with rigid materials [8], that can only be fully taken into advantage with suitable processing methods.

In this scope, additive manufacturing technologies are gaining increasing attention, base on being more environmental-friendly, allowing miniaturization of the devices, and simple three dimensional shapes [9].

Further, never as today these advantages can be taken to another level with additive manufacturing and tuning materials response over time: in this situation, not just 2D or 3D multifunctional materials will be implemented, but also 4D materials, with specifically designed time response [10].

The aforementioned challenges and future trends will drive the main research activity in this field, allowing the development of a new generation of lightweight smart and multifunctional functional materials for an increasing number of applications, strongly contributing both to the internet-of-things concept though stimuli responsive materials and to important need of environmental friendlier materials and technologies.

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