2011 2nd International Conference on Environmental Science and Development
IPCBEE vol.4 (2011) © (2011) IACSIT Press, Singapore

Polymer Composites Sustainability: Environmental Perspective, Future Trends and Minimization of Health Risk

V.P. Sharma, V. Agarwal, S. Umar and A. K. Singh
Developmental Toxicology Division
Indian Institute of Toxicology Research
(Council of Scientific & Industrial Research),
Lucknow, India
E mail ID: vpsitrc1@rediffmail.com

Abstract—**Polymer science is an interdisciplinary field as it involves the synthetic polymers, biopolymers, polymer characterization, designing and fabrication of new innovative products related to safer and sustainable environment. Polymeric composite materials have the base matrix of polymers containing the reinforcement fillers and additives. They have a wide array of applications ranging from packaging, spacecrafts, smart or specialized polymers to nano based textile material and biological implants. Different polymers used as matrix material to prepare composites with improved mechanical, thermal and electrical properties includes plastics of different constitution like polyester, polyamide etc. Growing public concern about environmental pollution has led to development and design of biodegradable composite materials. Knowledge and implementation of relevant regulatory guidelines are vital from safety and environmental viewpoint. New methods are being devised for polymerization using super critical CO_2 along with additives. They have potential market applications along with the elimination of toxic moieties generated in conventional manufacturing techniques. Green chemistry concepts may be utilized for eco-friendly materials and to minimize the toxic implications of organic chemicals such as toluene, methylene chloride which pose potential risks to human health. The holistic and concerted efforts are needed for the development of new composites for minimization of environmental impact of polymer composite production. The life cycle assessment is of paramount importance at every stage of a product's life from initial synthesis to final disposal for a sustainable environment. The regulatory assessment and monitoring procedures as per the National/International guidelines are required to be reviewed wherever needed. They must be updated periodically depending upon the composition, intended usage conditions in order to promote clean processing, applications, biodegradation, recycling and reprocessing.**

Keywords: Polymer Composite; Environmental Sustainability; Green Chemistry; Regulatory Requirements; Biodegradation.

I. INTRODUCTION

Plastic industry has a vast and yet unused potential for the sustainable formation of our economic, social and ecological environment. Polymer composites mark the beginning of a new era of the polymer industry towards the sustainable development. In fact, the current demand for materials that are both light and strong has been the main force driving the development of composites. They are made up of two components namely the matrix or binder, which surrounds and binds together a cluster of fibers or fragments of another component which is the reinforcing material or filler. Composite materials are being used in a wide array of applications *viz.* spacecrafts, defense products, biomedical implants [1], alternate building and construction materials [2] by virtue of their strength, stiffness and lightness. The in-service properties of the composite are largely dependent upon the combination and the relative ratio of the matrix and the filler. By the proper selection of reinforcement and matrix material, manufacturers can produce properties that can exactly fit the requirements for a particular purpose. The novel material behavior, which for example combines a gain in hardness with additional toughness, is based on the large proportion of inner boundary present in these materials. Polymer composite have replaced a variety of traditional materials in different sectors by virtue of the desired properties like light weight, durability, heat resistance, reduced wear & tear, flexibility, chemical resistance and longer shelf life that can be achieved by making minor alterations in their compositions.

For long term benefits, the principles of sustainability should be brought into action in the day-to-day operations and requires a considerable commitment of effort and resources. It is a comprehensive approach that balances financial, environmental and social considerations. Innovative green products should be promoted that meet the specific requirements of markets and consumers. The modern sustainability parameters include use of renewable resources, waste prevention, biodegradability, percent recycled, transportation, price, health hazards, and energy use. The modification of polymer composites by using nano scale particles opens the door to new and extremely efficient nanocomposites. Therefore the development of stable nanocomposites which can be easily processed is a preeminent task for the future. These technologies shall not only fulfill our ecological but also our economic and social needs. Their development is intrinsically tied to new technologies which are made possible by advance research.

II. BIOBASED POLYMER COMPOSITES: A NEED FOR ENVIRONMENTAL SUSTAINABILITY

Polymers composites from renewable resources have attracted an increasing amount of attention over the last two decades due to environmental concerns and rapidly depleting conventional energy resources [3]. Several studies have reported the migration of polymer additives, unreacted monomers, catalyst remnants, polymerization solvents of low molecular mass fractions from the synthetic composites in to the packaged food materials with consequent toxic health implications to the consumers. Polyvinyl based composites may release dioxin and furans on combustion. Fiber glass has increased in popularity since the discovery due to its low toxicity. The rapidly increasing environmental pollution demands for novel biodegradable polymers especially for food packaging applications. Biocomposites are new light weight environmentally friendly structural materials where either/both the polymer matrix and the reinforcement originate from biomass. The natural fibres and plant based resins have been shown to combine the low cost composite with good mechanical properties [4]. The use of natural fibers as a replacement for synthetic fibers has received global attention. The hard fiber quality is the most commonly used in composite applications. Natural fiber reinforcements could considerably lower the price of bio-based composites that is still the higher barrier for their widespread application. Moreover, since they are derived from renewable sources, they can represent environmental friendly alternatives to conventional reinforcing fibers (glass, carbon, Kevlar) [5]. The natural fibers possess excellent tensile strength, modulus, high durability, low bulk density, good mouldability and recyclability. These fibers have an advantage over synthetic fibers in being less expensive, easily available and having a high specific strength [6]. The high stiffness and strength of these materials makes them suitable for numerous applications including industrial and domestic sectors. It is anticipated to have potential applications with elimination of the toxic by- products generated in conventional polymer manufacturing. Principles of green chemistry can be useful to achieve the objective of cleaner processing, applications and disposal.

In future manufacturers may be able to utilize green nanotechnology for eco friendly composite production and control the use of hazardous volatile organic compounds and solvents viz. Toluene, Methylene Chloride, which presents risk to human health and biodiversity. Exposure to these organics may cause cancer, eye, nose and throat irritation, headaches, loss of coordination, nausea, damage to liver, kidney, and central nervous systemSupercritical carbon dioxide ($scCO_2$) is promoted nowadays as a processing solvent in the formation of polymer composites in order to avoid the use of hazardous conventional organic solvents [7]. The new methods are being devised for polymerizing conventional monomers using super critical CO_2 along with added stabilizers. Supercritical CO_2 is a highly pressurized form of chemically benign gas that has properties of a liquid. Though conventional wood composites have a high degree of customer acceptance and market demand, there are reports indicating that Poly Brominated Diphenyl Ethers (PBDEs) and Hexa Bromo Cyclo Decanes (HBCDs) present as bio accumulative products in the environment [8]. They are used as additives in synthesis of conventional polymer based products, foams, electronics, fabrics, building insulation materials, furniture, electrical equipments etc. The level of concentration may vary and thus there is a need of complete understanding of mechanism of toxicity of such chemicals and the potential for additives and synergistic effects. The R&D organizations around the globe are experimenting with plant based plastics with different properties, as alternatives to lower the CO_2 emissions and to reduce the use of petroleum as the oil stocks are rapidly decline. The integrated waste management of plastic products is desirable for managing the waste in an economically sustainable environment. For e.g. 5- Hydroxy Methyl Furfural (HMF) is being converted into Furan Di Carboxylic Acid (FDCA) to serve as petroleum based precursor for the fabrication of plastic bottles. Biocomposites based on poly(3-hydroxybutyrate) (P3HB), poly(4-hydroxybutyrate) (P4HB), and poly(3-hydroxybutyrate-co-4-hydroxybutyrate) (P3/4HB) are suggested as a scaffold for critical biomedical applications such as heart valve tissue engineering or direct implantation [9]. Studies show that biodegradable polymer/hydroxyapatite (HA) composites have potential application as bone graft substitutes [10]. The practices are to be adopted for efficient disposal or collection of solid waste to avoid adverse effect on public health.

III. NANOCOMPOSITES- THE FUTURE TRENDS

New formulation of polymers and nanoparticles is opening new research pathways for engineering flexible composites that exhibit advantageous electrical, optical or mechanical properties. The mixing of nanoparticles with polymers to form composite materials has been practiced for decades [11]. Nanotechnology provides considerable opportunities for the development of sustainable innovative materials for agriculture, water treatment, food production, processing, preservation and packaging applications. However, our knowledge towards the nanomaterials toxicity is limited so there is a vital need for the beforehand consideration of the food contact safety implications of this vast technology. The superlative mechanical properties of carbon nanotubes make them the filler material of choice for composite reinforcement [12].Nano materials exhibit novel functionalities due to much larger surface to mass ratio in contrast to other conventional materials Nowadays biodegradable nanocomposites are being developed using Lyotropic Liquid Crystalline Media as a sustainable and eco friendly technology promoting the concept of green chemistry [13]. Homogeneous carbon nanotube/polymer composites achieve the electrical conductivity levels required for various electrical applications without compromising the host polymer's other preferred physical properties and processability [14]. Nanoclay polymer composites of polyamides, polyethylene, polystyrene, nylons and polyethyleneterephthalate are applied in multilayer film packaging [15]. Nowadays, nano particles of metals and metal oxides are used as fillers in certain composites by virtue of their biocidal properties in order to preserve the packaged food. The discovery of antimicrobial properties of nanozinc oxide and nanomagnesium oxide provide a new class of materials as fillers for effective food packaging composites [16].

There is a critical need for establishing processing techniques that are effective on the nano scale yet are applicable to economically viable processing. Major hurdle to the commercial use of nanocomposites is the absence of detailed structure-property relationships and effective processing techniques effective at both the nanoscale as well as at the microscopic levels. There is a need of multi-layered structured composites in which each sublayer contributes a distinct function to yield a mechanically integrated, multifunctional material. Nanocrystals with polymers has attracted great interest mainly due to the wide potentials of nanocrystal-polymer composites in optical displays, nonlinear optical devices and biological encoding.

IV. CONCLUSION

There is a worldwide realization of the damage that a rapidly rising indiscriminate industrial processes can do to the ecology and environmental balance of the planet. There is general agreement that future technology development will need concepts such as biological sustainability, minimum use of energy and renewable raw materials that will probably be set internationally. Current R&D needs emphasizes on the development of high-value and safer products. Advanced composite materials are being seen to have benefits compared with traditional materials in many of these areas, particularly in low energy consumption during manufacture, construction and subsequent building operation. The suitability assessment of the finished products is of paramount importance at every stage from initial synthesis to final disposal for a sustainable environment. This includes green synthesis, processing, applications, recycling and bio-degradation. Although there are environmental problems associated with material manufacture, particularly resins, a number of farsighted manufacturers are already improving this aspect significantly. Glass Fibre Reinforced Plastic requires relatively low energy during manufacture compared with metal structures; it has much lower thermal conductivity and is more durable. The current use of advanced polymer composites in the foreseeable future is likely that the main utilization of these materials will be in conjunction with the more conventional materials. The plastic products should be manufactured as per the regulatory guidelines, evaluated for their characteristics and ensure to minimize the adverse effect on human health and biodiversity. Combination of nanotechnology with biocomposites can be promising tool to achieve the target of environmental sustainabity.

REFERENCES

[1] S. Ramakrishna, J. Mayer, E. Wintermantel and K.W. Leong, "Biomedical applications of polymer-composite materials: a review,'' Composites Science and Technology, vol 61(9), pp. 1189-1224, July 2001.

[2] L.C. Hollaway, "The evolution of and the way forward for advanced polymer composites in the civil infrastructure," Construction and Building Materials, vol 17(6), pp. 365–37, October 2003.

[3] M. Avella, A. Buzarovska, M. E. Errico, G. Gentile and A. Grozdanov, "Eco-Challenges of Bio-Based Polymer Composites," Materials, vol *2*(3), pp. 911-925, August 2009.

[4] L. Yu, K. Dean and Lin Li, "Polymer blends and composites from renewable resources," Progress in Polymer Science, vol. 31(6), pp. 576-602, June 2006.

[5] A. K. Mohanty, M. Misra and L. T. Drzal, "Sustainable Bio-Composites from Renewable Resources: Opportunities and Challenges in the Green Materials World," Journal of Polymers and the Environment, vol. 10(1/2), pp.19-26, May 2002

[6] K. Oksman, M. Skrifvars and J. F. Selin, "Natural fibres as reinforcement in polylactic acid (PLA) composites", Composites Science and Technology, vol. 63 (9), pp. 1317-1324, July 2003.

[7] S. P. Nalawade, F. Picchioni and L.P.B.M. Janssen, "Supercriticalcarbon dioxide as a green solvent for processing polymer melts: Processing aspects and applications," Prog. Polym. Sci., vol. 31, pp. 19–43, October 2006.

[8] A. Schecter et al., "Poly Brominated Diphenyl Ethers (PBDEs) and Hexa Bromo Cyclo Decanes (HBCDs) in composite U.S food Samples", Environmental Health Perspective, vol. 118 (3), pp. 357-362, March 2010.

[9] C. Stamm, A. Khosravi, N. Grabow, K. Schmohl, N. Treckmann, A. Drechsel, M. Nan, K. P. Schmitz, A. Haubold and G. Steinhoff, "Biomatrix/Polymer Composite Material for Heart Valve Tissue Engineering," Ann. Thorac. Surg., vol. 78, pp. 2084-209, March 2004.

[10] S. C. Rizzi, D. Heath, A.G.A. Coombes, N. Bock, M. Textor and S. Downes, "Biodegradable polymer/hydroxyapatite composites: surface analysis and initial attachment of human osteoblasts," Journal of Biomedical Materials Research, vol. 55(4), pp. 475-486, May 2009.

[11] A. C. Balazs, T. Emrick and T.P. Russell,"Nanoparticle Polymer Composites: Where Two Small Worlds Meet," Science, vol 314, pp. 1107-1110, November 2006.

[12] J. N. Coleman, U. Khan, W. J. Blau and Y. K. Gun'ko, "Small but strong: A review of the mechanical properties of carbon nanotube–polymer composites," Carbon, vol. 44, pp. 1624-1652, August 2006.

[13] J. D. Clapper and C. A. Guymon, "Nanostructured Biodegradable Composites Generated Using Lyotropic Liquid Crystalline Media," Macromolecules, vol. 40 (22), pp 7951-7959, September 2007.

[14] R. Rajagopal, C. Jian and L. Haiying, "Homogeneous carbon nanotube/polymer composites for electrical applications," Applied Physics Letters, vol. 83, pp. 2928-2930, October 2003.

[15] FAO/WHO Expert Meeting on the Application of Nanotechnologies in the Food and Agricultural Sectors: Potential Food Safety Implications: Meeting Report, Rome, pp.104 ,2009

[16] L. Zhang, Y. Jiang, Y. Ding, M. Povey and D. York, "Investigation into the antibacterial behavior of suspensions of ZnO nanoparticles (ZnO nanofluids)," J. Nanoparticle Res., vol. 9 (3), pp. 479-489, October 2007.