BIODEGRADABLE POLYMERS AND COMPOSITES WITH SHAPE MEMORY: A MINI REVIEW

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ABSTRACT

Since their inherent properties, polymers and polymer-based materials have become superior end-use materials as material technology has advanced. When exposed to microorganisms, aerobic and anaerobic processes, biodegradable polymers' chemical and physical properties deteriorate and total breakdown. These natural degradable polymers can be obtained from renewable sources and improved through blending and composite forming techniques, yielding new blends with high efficiency, strength, and processability properties. A discovery in biodegradable polymers is their extraordinary ability to be stimulated by temperature, known as a thermal sensitive shape memory polymer (SMP). As a result, the development of biodegradable polymers such as poly(lactic) acid (PLA) and poly(1,8-octanediol-glycerol-1,12-dodecanedioate) (POGDA) blends and composites with other reinforcing fillers will be reviewed in this article.

Keywords: shape memory polymers, biodegradable, composites, thermoresponsive, polylactic acid.

INTRODUCTION

Shape memory polymers (SMPs) and their composites are emerging smart materials with applications ranging from biomedical [1] to construction engineering [2]to aerospace[3]. In the current scenario, polymers are gaining popularity due to their reversible or irreversible nature, which can change properties in response to external stimuli such as pH, light, temperature and magnetic field or electric[4]. Because external stimuli can tune and manipulate their properties in a controllable manner, they are well suited for designing smart materials that can be used in various applications. SMP have a permanent shape at room temperature, deform at a high transition temperature (Ttrans), and retain the deformed shape after cooling, reheating causes them to revert from the deformed shape to the permanent shape. The shape memory effect has been discovered in various polymers, including amorphous polymers[5, 6]. Thermally sensitive SMPs typically have a physical crosslinking structure, crystalline/amorphous hard phase, or chemical cross-linking structure. As a switch, a low temperature transition or crystalline, amorphous or liquid-crystal phase. Internal stress is generally zero or very low in permanent shapes. If the SMP is deformed, large amounts of internal stress can be stores in the cross-linking structure by cooling the polymer below to its switch transition temperature. The SMP recovers its permanent shape by heating the polymer above the switch transition temperature, releasing internal stress stored in the cross-linking structure. SMPs while superior in some ways to shape memory alloys (SMAs) [7], have significant shortcoming in terms of mechanical strength and shape recovery stress. Using high modulus inorganic and organic fillers is one of the most immediate ways to reinforce pristine SMPs[8]. The primary goal of this review is to go over the blends of shape memory blends-based polyester and blends composites that can be used as biomaterials in biomedical applications.

BIODEGRADABLE SHAPE MEMORY POLYESTER BLENDS

Many new polymerization strategies, such as thermal polycondensation have been investigated to develop biodegradable polymers for various biomedical applications. In terms of feasibility, a catalyst -free polycondensation technique for preparing polyol-based biodegradable polyesters is appealing [9, 10]. However, blending conditions and processes strongly influence the physical properties of polymer blends, which affect the level of mixing of the blends. The excellent biodegradability and biocompatibility in biodegradable polyester have recently gained much attention. Poly- lactones such as polylactic acid (PLA), poly-glycolic acid (PGA), and their co-polymers are rapidly becoming the most widely used polymers for biomedical devices fixation [11]. Lee et al. (2016) has synthesized Poly(1,8-Octanediol-Glycerol-1,12-Dodecanedioate) (POGDA) as a new thermoresponsive biodegradable polyester[12]. PLA and POGDA are degradable polyester-based polymers with a wide range of properties that can be achieved by modifying monomers and synthesized conditions.

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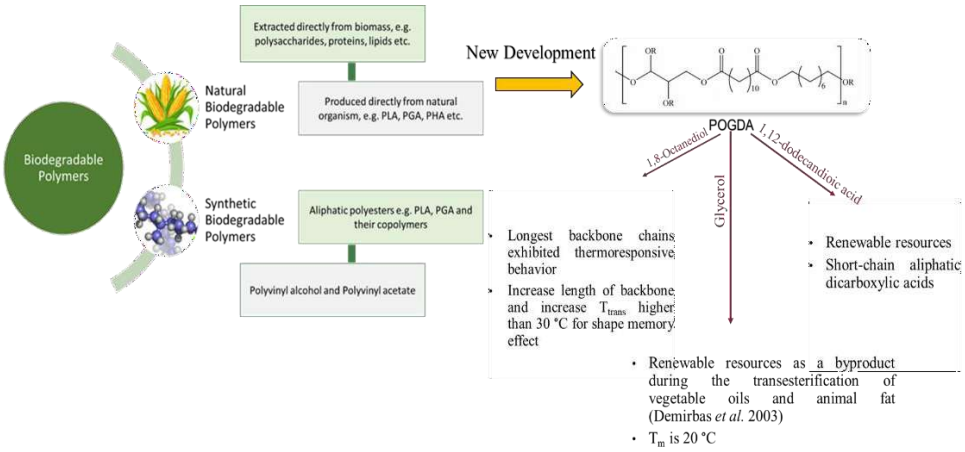

Fig. 1: Classification of biodegradable polymers [12]

MECHANISM OF STIMULI-RESPONSIVE POLYMERIC MATERIALS

On a microscopic level, the intermolecular structure of SMPs can be divided into two major components: net point (hard segment) and switching (soft segment). Generally, both parts are required for the shape memory effect (SME) to be achieved in SMPs. The net point, which is connected by chain segments, provides entropic elastic and determines the permanent shape of an SMP. Aside from that, net points serve as network conjunctions, helping to stabilize the network throughout the thermomechanical process [13]. While switching segment, on the other hand is in charge of maintaining the temporary shape due to its ability to reversible change phase upon stimulation, where the network chain is flexible at temperature above the transition temperature (Ttrans) but rigid at temperatures below Ttrans. Conventional SMPs are typically made up of polymer chains that move in different direction across Ttrans. The amorphous phase transition behavior give rise to the most primitive one-way SMPs [14]. The amorphous phase occupies a specific polymer region, determining the glass transition (Tg) region. When the temperature reaches Tg, the polymer becomes more pliable and deformable than at room temperature. At this point, the polymer transitions from a glassy to a rubbery state. Under external stress, the molecular chain becomes flexible enough to be stretched, coiled, or bent, resulting in polymer deformation. Depending on the molecular chain structure, the Tg range can be board or narrow [13, 15, 16].

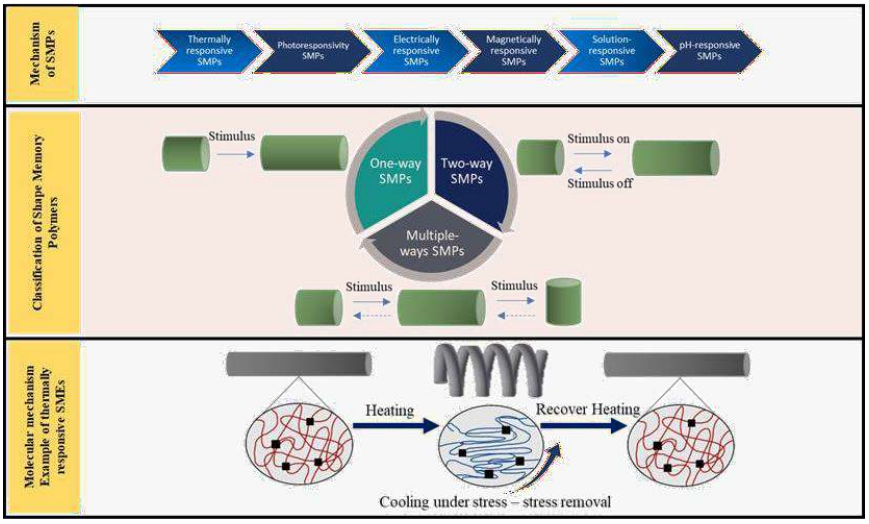

Fig. 2: Mechanism and classification of shape memory polymers with example of thermally responsive shape memory effects

BIODEGRADABLE POLYESTER BASED COMPOSITE

Composites are traditionally formed by combining two or more individual components with distinct properties to create a functional material. PLA can make composite materials as reinforcement and a matrix. Adding different fillers to the PLA matrix can improve its inherent properties, ensuring the commercial viability of PLA-based biomedical and packaging products [17].

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TABLE 1: Polymer physical properties (L-lactic acid)

Authors	Physical property	Values for L-lactic acid
Casalini et al., [18]	Glass transition temperature	55-65°C
	Melting temperature	170-200°C
	Melt crystallization temperature	90 and 120°C
	Viscosity	1.24-1.30 g/cm^3
	Elastic modulus	2.7-4.1 GPa
	Tensile strength	15.5-150 MPa

CONCLUSIONS

Future opportunities will arise for biodegradable products to replace (or even replace) nonbiodegradable equipment. Compostable polymer composites could replace most existing materials in the future, which is crucial for human sustainability. Therefore, analyzing nanofillers to improve biodegradable, lightweight structures is a challenge.

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REFERENCES

[1] W. Zhao, L. Liu, F. Zhang, J. Leng, and Y. Liu, "Shape memory polymers and their composites in biomedical applications," *Mater Sci Eng C Mater Biol Appl*, vol. 97, pp. 864-883, Apr 2019, doi: 10.1016/j.msec.2018.12.054.

[2] A. Sellitto and A. Riccio, "Overview and Future Advanced Engineering Applications for Morphing Surfaces by Shape Memory Alloy Materials," *Materials (Basel)*, vol. 12, no. 5, Feb 28 2019, doi: 10.3390/ma12050708.

[3] G. Costanza and M. E. Tata, "Shape Memory Alloys for Aerospace, Recent Developments, and New Applications: A Short Review," *Materials (Basel)*, vol. 13, no. 8, Apr 15 2020, doi: 10.3390/ma13081856.

[4] Bratek-Skicki, "Towards a new class of stimuli-responsive polymer-based materials –Recent advances and challenges," 2021, doi: https://doi.org/10.1016/j.apsadv.2021.100068.

[5] E. M. Zirdehi, H. Dumlu, G. Eggeler, and F. Varnik, "On the Size Effect of Additives in Amorphous Shape Memory Polymers," *Materials (Basel)*, vol. 14, no. 2, Jan 10 2021, doi: 10.3390/ma14020327.

[6] W. Yuan et al., "Stress-Free Two-Way Shape Memory Effects of Semicrystalline Polymer Networks Enhanced by Self-Nucleated Crystallization," *ACS Macro Lett*, vol. 9, no. 9, pp. 1325-1331, Sep 15 2020, doi: 10.1021/acsmacrolett.0c00571.

[7] B. Yuan, M. Zhu, and C. Y. Chung, "Biomedical Porous Shape Memory Alloys for Hard-Tissue Replacement Materials," *Materials (Basel)*, vol. 11, no. 9, Sep 13 2018, doi: 10.3390/ma11091716.

[8] M. H. Mat Yazik et al., "Effect of Nanofiller Content on Dynamic Mechanical and Thermal Properties of Multi-Walled Carbon Nanotube and Montmorillonite Nanoclay Filler Hybrid Shape Memory Epoxy Composites," *Polymers (Basel)*, vol. 13, no. 5, Feb 25 2021, doi: 10.3390/polym13050700.

[9] A. C. D. Pfluck, D. P. C. d. Barros, and a. L. P. Fonseca, "Biodegradable Polyester Synthesis in Renewed Aqueous Polycondensation Media: The Core of the New Greener Polymer-5B Technology," *MDPI*, 2021, doi: https://doi.org/10.3390/pr9020365.

[10] Marina Sokolsky-Papkova, Robert Langerb, and A. J. Domba, "Synthesis of aliphatic polyesters by polycondensation using inorganic acid as catalyst," 2009, doi: 10.1002/pat.1541.

[11] T. V. Shah and D. V. Vasava, "A glimpse of biodegradable polymers and their biomedical applications," *e-Polymers*, vol. 19, no. 1, pp. 385-410, 2019, doi: doi:10.1515/epoly-2019-0041.

[12] X. Y. Lee, Wahit, M. U., & Adrus, N, "Biodegradable and temperature-responsive thermoset polyesters with renewable monomers," 2016, doi: https://doi.org/10.1016/j.trsl.2014.01.014.

[13] Y. Xia, Y. He, F. Zhang, Y. Liu, and J. Leng, "A Review of Shape Memory Polymers and Composites: Mechanisms, Materials, and Applications," *Adv Mater*, vol. 33, no. 6, p. e2000713, Feb 2021, doi: 10.1002/adma.202000713.

[14] H. M. Dou, J. H. Ding, H. Chen, Z. Wang, A. F. Zhang, and H. B. Yu, "Bio-based, biodegradable and amorphous polyurethanes with shape memory behavior at body temperature," *RSC Adv*, vol. 9, no. 23, pp. 13104-13111, Apr 25 2019, doi: 10.1039/c9ra01583c.

[15] K. Yu and H. J. Qi, "Temperature memory effect in amorphous shape memory polymers," *Soft Matter*, vol. 10, no. 47, pp. 9423-32, Dec 21 2014, doi: 10.1039/c4sm01816h.

[16] M. T. Kawai T, "Plastic molded articles with shape memory property," European patent EP19890300839. 21 Dec 1994.

[17] S. Q. c. Shan Liu, d, Min He c,d, Dengfeng Zhou a,b, Qingdong Qin a,b, Hao Wang e,**, "Current applications of poly(lactic acid) composites in tissue engineering and drug delivery," 2020, doi: https://doi.org/10.1016/j.compositesb.2020.108238.

[18] T. Casalini, F. Rossi, A. Castrovinci, and G. Perale, "A Perspective on Polylactic Acid-Based Polymers Use for Nanoparticles Synthesis and Applications," Front Bioeng Biotechnol, vol. 7, p. 259, 2019, doi: 10.3389/fbioe.2019.00259.

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