Recent Advances in Biodegradable Polymers and Fibers

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Recently, biodegradable and bioabsorbable polymers have been attracting much attention in various fields. These polymers can readily be hydrolyzed into digestible metabolites in natural environment as well as in living tissues, so that they would not remain or accumulate in the biospheres including human organisms after use. Historically, the studies both on the biomedical and bioplastic applications of these polymers started more than thirty years ago. The trial to use them as plastics, however, was slowed down, while the biomedical application has progressed rather steadily until now. In late 1980s, an urgent need for the preservation of the global environment was realized and stimulated the researches on biodegradable plastics and plastic recycling. In this presentation the recent status in the development of biodegradable polymers and fibers will be surveyed.

Biodegradable polymers for practical use

A wide variety of screening tests on possible biodegradable polymers have been carried out for the past several years, and three types of aliphatic polyesters have come out as practically usable bioplastics which have good degradability in natural environment and show proper cost performance. These are poly(L-lactic acid) (PLLA), poly(3-hydroxybutyrate/3-hydroxyvalerate) (PHB/HV), and poly(alkylene succinate) (PBS).

$$-\!\!\left(\mathrm{OCH(CH_3)CO}\right)_n\!\!- \qquad \text{PLLA}$$

$$-\!\!\left(\mathrm{OCH(CH_3)CH_2CO}\right)_m\!\!\left(\mathrm{OCH(C_2H_5)CH_2CO}\right)_n\!\!- \qquad \text{PHB/HV}$$

$$-\!\!\left(\mathrm{O(CH_2)_4O\text{-}CO(CH_2)_2CO}\right)_n\!\!- \qquad \text{PBS}$$

Their biodegradability was confirmed by the composting test, although their degradability in other environments was found to be somewhat different. Since these polymers have different mechanical properties as summarized in Table 1, they seem to possess their own applications as films, sheets, injection moldings, or fibers depending on their characteristics. At present, new synthetic methods for these polymers, both biological and chemical, are proposed in order to reduce their costs furthermore.

With these developments, biomedical application of the biodegradable polymers is also investigated because this class of aliphatic polyesters has been known to be highly biocompatible. This application may cover bioabsorbable sutures, temporary replaces of human organs, and drug carriers. More recently, the application of bioabsorbable polymers to the guided tissue regeneration (GTR) technique has been proposed in which human tissues can be regenerated on a specially designed polymeric scaffold. For controlling the cell growth and bioabsorption rate of the scaffold, functional derivatives of the above polymers are designed.

Table 1. Characteristics of typical biodegradable polymers

Polymer	Trade name (Supplier)	mp (°C)	Tensile strength (kg/cm^2)	Tensile elongation (%)	Flexural modulus (ton/cm^2)
PLLA	Lacty (Shimadzu)	171	590	2	30.4
PHB/HV	Biopol (Zeneca)	154 164	240	7	9.3
PBS	Bionolle (Showa Highpolymer)	113	310	350	6.5
PCL[a]	Placcel (Daicel)	57	150	430	3.6
Starch/PVA[b]	Mater-Bi (Nihon Gousei Kagaku)	132	220	125	10.3

a) polycaprolactone b) poly(vinyl alcohol)

Biodegradable fibers

Various biodegradable fibers are prepared by melt-spinning of the above polymers and used as biomedical appliances and commodity goods. Suture is one of the most popular application of the biodegradable fibers. Until now, several absorbable sutures have been developed based on polyglycolide (PGA) and its derivatives. Table 2 shows the properties of the commercially available sutures as compared with those of the relevant biodegradable fibers. Both the filaments of polyglycolide and polyglactin are too hard for biotissue because of their high modulus, and the braided filaments are prepared for use. Monofilament type sutures were developed from the copolymers of glycolide and other cyclic monomers for which the modulus of fiber was reduced by decreasing the glass transition temperature of the base polymer. These fibers used as sutures have a rather short life in terms of strength in biotissues, i.e., from 2 to 5 weeks which may be comparable to the curing time of wound. Such biopolymers as collagen and chitin are likely to lose their original mechanical properties by water adsorption and to stimulate bioreactions in tissues, and their fibers are mainly used for making the artificial wound cover attributes in wool form.

The biodegradable fibers for the general purpose use have also been developed quite recently based on PLLA and polycaprolactone (PCL). These fibers should have a relatively longer life in natural environment, e.g., from 3 months to 2 years, and should be promptly degraded after use. It was confirmed that both PLLA and PCL fibers can be degraded shortly after they are put into compost. Irrespective to this property, PLLA fiber is attracting a special interest as a new element material for clothing. PHB/HV is very difficult to make strong fiber by melt-spinning, although it seems to be suitable for use as fish strings and nets in terms of degradability and potential mechanical properties. The author is now studying the spinning of all of these aliphatic polyesters including PBS in order to analyze the structure-property relationship of these fibers.

Table 2. Properties of typical biodegradable fibers.

Fiber	Strength (MPa)	Modulus (GPa)	Elongation (%)	mp (°C)	Trade name
Suture					
Polyglycolide	890	8.4	30	230	Dexon, etc.
Polyglactin[a)]	850	8.6	24	220	Vicryl
Polydioxanone	490	2.1	35	106	PDS
Polygluconate[b)]	550	2.4	45	213	Maxon
Polyglecaprone[c)]	400	1.2		200	Monocryl
Cutgut	520				
Synthetic skin					
Chitin	750		12		Beschitin
Collagen	360	4.0	20		Biobren
Commodity					
Poly-L-lactide	550	5.0	35	178	Lactron
Polycaprolactone	800		27	60	

Copolymers of glycolide (90) with (a) lactide, (10) (b) trimethylene carbonate (10), and (c) ε-caprolactone (10).