A novel polyester urethane based on lactic acid and polyethylene glycol 400 (PEG400) was synthesized. The biodegradation of the polyester urethane under soil burial condition and by cultured bacteria (Pseudomonas aeruginosa) at different temperatures (5, 15, 37°C) was studied. The biodegradation was assessed from the weight loss, tensile strength and ultimate elongation as well as chemical changes by FTIR spectroscopy and visual changes by optical and scanning electron microscopy. After 30 days of exposure of the polyester urethane films to cultured Pseudomonas aeruginosa around 33-36% degradation in terms of weight loss was observed. Under soil burial degradation the samples have shown 62% weight loss in 180 days but there is around 98 to 99% loss in tensile strength and elongation at break.

Keywords: Polyester urethane, Biodegradation, Soil, Bacteria, Tensile strength, Elongation at break

IPC Code(s): C08G63/00, C12P1/00

There has been a great deal of interest in the synthesis and properties of polyurethanes, which find extensive industrial and biomedical applications. Biodegradation of polyurethane was established by the early investigations of Osserfort and Testroet. In recent years biodegradability of polyurethanes has been studied more carefully, taking into account the diversity of polyurethane materials. The interest on biological degradation and biological stability of polyurethanes arose as these polymers found application in various fields. Biostability is required in the application of polyurethanes as implants in cardiac pacemakers leads, vascular grafts and artificial hearts. On the other hand, biodegradability is expected from polyurethanes, which are to be used for, e.g., short time implants such as tissue engineering scaffold and in the case of biological degradation of polyurethane solid wastes.

The degradation of polymers may occur via photochemical, thermal, or biodegradation processes. Of these, biodegradation is much more simple, economic, and occurs in the actual conditions of waste disposal. The main attacking agents in biodegradation are microorganisms, e.g., actinomycetes, fungi, and bacteria, which are widely spread in soil, water, and air. One of the potential approaches to rendering the synthetic polymers microorganism susceptible is to incorporate a biodegradable structural unit into the polymer backbone. Polyurethane has gained market acceptance as a material for biomedical application. Chemical modification of polyurethanes via incorporation of a biodegradable structural unit (i.e., an ester group) into the main chain is a pragmatic approach, imparting more susceptibility to microbial attack under normal hydrothermal usage conditions. Polyester urethane is susceptible to assimilation by fungi and bacteria. Darby and Kaplan found that polyurethanes based on aliphatic polyester diols were more susceptible to fungal attack than those based on polyether diols. Polyurethane degrading microorganisms including Fusarium solani, Curvularia senegalensis, Aureobasidium pullulans and Cladosporidium sp. were found and esterase activity was detected with Curvularia senegalensis. A number of bacteria were also claimed to be capable of degrading polyurethanes and there are four strains of Acinetobacter calcacecicus, Arthrobactor globiformis, Pseudomonas aeruginosa, Pseudomonas cepacia, Pseudomonas putida and two other Pseudomonas like species. Comamonas acidovorans TB-35 was also reported and it was isolated from soil samples due to its ability to degrade polyester urethane. In addition, Pseudomonas chlororaphis was also isolated and...
encoded a lipase responsible for the degradation of polyester urethane. Kay et al. investigated the ability of 16 bacterial isolates to degrade polyester urethane in a large-scale test of bacterial activity against polyurethanes. Two isolates, Corynebacterium sp. and Pseudomonas aeruginosa could degrade polyester in the presence of basal media. However, none of the isolates grew on polyurethane (PU) alone. Physical tests of the degraded polyester PU revealed different but significant decrease in tensile strength and elongation for each isolates. Kay et al. tested the chemical and physical changes in degraded polyester PU. Polyurethanes taken from Corynebacterium sp. cultures had significant reductions in both tensile strength and elongation after three days of incubation. Infra-red spectrophotometer analysis revealed the ester segment of the polymer to be the main site of attack.

This paper reports the biodegradation of a lactic acid and polyethylene glycol based polyester urethanes under soil burial condition and biodegradation by cultured bacteria (Pseudomonas aeruginosa) at different temperatures. The biodegradation of the polyester urethane was assessed from the weight loss, tensile strength and ultimate elongation as well as chemical changes by FTIR spectroscopy and visual changes by optical and scanning electron microscopy.

**Experimental Procedure**

**Materials**

- Lactic acid (88%) (LA), Quest Chrmicals, India; polyethylene glycol 400 (PEG 400), E. Merck, India; dibutyltindilaurate (DBTDL), Fluka AG (used without purification); toluene diisocyanate (TDI), E. Merck, Germany (used as received); tetrahydrofuran (THF), E. Merck, India (dried over metallic sodium); sodium hydroxide pellet, Qualigens, India; benzene, Quest Chemicals, India; sulphuric acid, Quest Chemicals, India; sodium chloride, E. Merck, India; nutrient broth, Hi Media, India; bacteria (Pseudomonas aeruginosa), NCCS, Pune, India; doubly deionized water (Milli-Q-water, USA).

**Synthesis of polyester urethane**

Lactic acid and PEG400 based polyester urethane was synthesized as described elsewhere. For convenience, brief outlines of the synthesis are represented below.

**Synthesis of ester diol**

The ester diol was synthesized by reacting lactic acid (LA) with polyethylene glycol 400 (PEG 400) using sulphuric acid as catalyst. LA and PEG 400 were taken in 1:2 molar ratio in a round bottom flask equipped with an automatic water separator. The reaction mixture was refluxed for 10 h at 80°C. Water liberated due to esterification was removed as azeotropic mixture with benzene. The polyethylene ester diol was collected by vacuum distillation, as a colourless viscous liquid.

**Synthesis of polyester urethane**

Polyester urethane was synthesized by reacting the ester diol with 2,4-toluene diisocyanate (TDI) (NCO:OH = 2:1 and 2.5:1) taken in dry THF in presence of DBTDL as catalyst. The reaction was continued at room temperature (29°C) for 2 h with careful and controlled stirring. The viscous polymer solution was poured on a flat glass petridish for film casting. The casted film was left on the petridish exposed to atmospheric moisture for 24 h for slow curing followed by heating at 80°C for 5 h. This lactic acid and PEG400 based polyester urethane was designated as biodegradable polyurethane (BDPU).

**Soil burial degradation study**

**Preparation of test medium**

The soil, collected from the Indian Institute of Technology campus, Kharagpur, India, was first dried in the sun for two days. The dry soil was ground to powder after removing the coarse aggregates and stones by sieving. The dry soil was then supplemented with biomass (6 g/kg) to encourage an active microbial flora. The soil was also supplemented with fungal ribosome, Aspergeli origae, Pseudomonas species (100 µg/g) and Strepto coccus (150 µg/g). The processed soil was then placed on a large tray and ~200 mL water was spread slowly over the soil and the mixture was allowed to stand for 24 h so that the water could fully penetrate the soil. The soil was kept moist with water and stored at indoor under ambient humidity (36-92%) and temperature (25-32°C).

**Test method**

In typical tests, each of the polymer films (BDPU) to be tested for biodegradation was dried at 50°C under vacuum to constant weight. Each of the accurately weighed dry polymer films was then buried completely into the wet soil of the test medium and left for several days. The test medium was maintained...
at ambient temperature (25-32°C) with daily addition of water to replenish any loss on evaporation. Test samples were removed at time intervals of 15, 30, 60, 120 and 180 days, washed repeatedly with water to remove the soil adhered onto the surface of the films, and then dried under vacuum to constant weight. The polyester urethane samples degraded under soil burial condition for 15, 30, 60, 120 and 180 days are designated as BDPU15D, BDPU30D, BDPU60D, BDPU120D, BDPU180D respectively. BDPUc denotes control sample. The degradation of the polymer was then calculated using the formula

\[
\% \text{ Degradation} = \frac{(W_0 - W_d)}{W_0} \times 100
\]

where, \(W_0\) is the initial weight of the dry film and \(W_d\) is the weight of the degraded film.

**Bacterial degradation**

**Preparation of media**

The medium for bacterial degradation was prepared by dissolving 1.3 g nutrient broth in 100 mL distilled water. This solution was then taken in 10 bacterial culture tubes and the culture tubes containing the medium were autoclaved (15 lb/in², 121°C for 15 min).

**Bacteria inoculation**

Nutrient broth was used as the medium for bacterial growth. *Pseudomonas aeruginosa* (NCCS, Pune, India) (100 μL/10 mL media of the each culture tube) was inoculated under laminar flow of sterilized condition. Then the culture tubes were placed in the BOD incubator shaker. Growth of bacteria started after 12 h and continued for 24 h at 37°C.

**Degradation study of polyester urethane in cultured *Pseudomonas aeruginosa* at different temperatures**

BDPU samples were cut into standard dumbbell specimen and weights were taken. Each sample was sterilized by boiling in water for 20 min. Then the samples were further sterilized by 70% alcohol followed by washing with sterile water for five times. The sterilized PU samples were put into the cultured tubes, which contained the bacteria (*Pseudomonas aeruginosa*) in nutrient broth media. Polymer samples were also put into the culture tubes, which contained only the nutrient broth media without bacteria. Then

the cultured tubes with polymer samples were placed in the BOD incubator shaker and bacterial degradation was continued at different temperatures 5, 15, 37°C upto 30 days. The samples were designated as BDPUc, BDPU1P1, BDPU1P2, BDPU1P3, BDPU1P4, BDPU1P5. In BDPUc, the subscript c denotes the control polyurethane sample and in BDPU1P1, BDPU1P2, BDPU1P3, BDPU1P4, BDPU1P5, the subscripts P1, P2, P3, P4, P5 denote degraded polyurethane samples after 1, 7, 14, 21, 30 days respectively degraded by cultured *Pseudomonas aeruginosa*.

The degradation of the polyester urethane films in bacterial culture medium was then calculated following

\[
\% \text{ Degradation} = \frac{(W_0 - W_d)}{W_0} \times 100
\]

where, \(W_0\) is the initial weight of the dry film and \(W_d\) is the weight of the degraded film.

**Characterization**

**FTIR spectroscopic analysis**

FTIR spectra of non-degraded and degraded polyester urethane samples were taken using Thermo Nicolet FTIR, Model Nexus 870. The polyurethane films were cleaned thoroughly with acetone, dried and were kept in vacuum desiccator for 24 h. These films were used for FTIR analysis. The FTIR spectrum was taken in the frequency range of 400-4000 cm⁻¹.

**Optical microscopy**

Optical microscopy of BDPUc and soil microorganism degraded polyester urethane films (BDPU15D, BDPU30D, BDPU60D, BDPU120D, BDPU180D) were done using light microscopy (Leica). The samples were prepared and conditioned as done for FTIR analysis.

**Scanning electron microscopy**

Scanning electron microscopy of the control polyester urethane film and soil microorganism as well as cultured *Pseudomonas aeruginosa* degraded polyester urethane films was done using JEOL SEM, model JEOL-JSM 5800. The samples were prepared and conditioned as before.

**Tensile properties**

For testing of mechanical properties, prepared polyester urethane film samples before and after soil
burial degradation and cultured *Pseudomonas aeruginosa* degradation were conditioned by the following method. The polyester urethane films were kept in a vacuum desiccator overnight. Then the films were cut into standard dumbbell specimen and were subjected to test for various mechanical properties like tensile strength, elongation at break using Hounsfield UTM tensile testing machine.

**Results and Discussion**

In previous communication results of hydrolytic degradation of lactic acid and polyethylene glycol based polyester urethanes in water, phosphate buffer solution, sodium chloride solution, different mineral acids and in varying concentrations of sodium hydroxide solutions have been discussed. In this study major focus has been put on the investigations related to biodegradation of these polyester based polyurethanes by the attack of different microorganisms. The biodegradation of the polymers was evaluated in two major ways: First by monitoring the loss in weight of the polyurethane samples with the progress of degradation up to 180 days in case of soil burial exposure and 30 days in case of exposure to cultured bacteria *Pseudomonas aeruginosa*. Second monitoring was done by measuring the losses in tensile strength and elongation at break of the polyester urethane samples with the progress of degradation under both the exposure conditions. FTIR spectroscopic analysis as well as optical and SEM analyses of the degraded polyurethanes were carried out in order to have some insight on the structural changes in the polymer samples due to degradation by the attack of microorganisms.

**Soil burial degradation**

A systematic soil burial degradation for polyester urethane films was carried out for maximum 180 days under indoor normal hydrothermal conditions. The results of degradation in terms of weight loss are presented in Table 1. Each of the degraded polymer films was checked for transparency and brittleness at various stages of the test. The films gradually developed brittleness and translucency with the progress of degradation under soil burial condition. The gradual development of physical brittleness of the polymer films is indicative of strong bacterial attack. From Table 1 it is apparent that during soil burial period after a rapid initial weight loss, the degradation of the polyester urethanes became steady. Around 62% degradation occurred in 180 days soil burial condition. Since the soil was supplemented with fungal ribosome, *Aspergeli origae*, *Pseudomonas* species (100 µg/g) and *Strepto coccus* (150 µg/g) bacteria, it is, therefore, reasonable to assume that such extent of degradation occurred due to hydrolytic breakdown as well as due to the attack of microorganisms (bacteria and fungi) available in the soil. While under soil burial degradation the samples have shown 62% weight loss in 180 days but there is around 98 to 99% loss in tensile strength and elongation at break (Table 1). This 98 to 99% loss in tensile strength and elongation at break indicates almost a total loss of physical integrity of the polymer chains in the polyester urethane samples due to the break down of the polymer chains at the vulnerable sites like ester and urethane bonds. On the other hand 62% degradation in terms of mass loss accounts for the leaching of the smaller sized fragments of the degraded polymer chains while retaining physically anchored the bigger sized degraded polymer chain segments. This explanation can be supported with the FTIR spectroscopic as well as microscopic analyses.

**Bacterial degradation**

It is known that *Pseudomonas aeruginosa* can selectively degrade ester group by esterase enzyme. It was, therefore, decided to use cultured *Pseudomonas aeruginosa* for degradation of lactic acid based

<table>
<thead>
<tr>
<th>Sample</th>
<th>Soil burial time (days)</th>
<th>Degradation of polyester urethane (% wt loss)</th>
<th>Tensile strength (MPa)</th>
<th>% Loss of T.S.</th>
<th>Elongation at break (%)</th>
<th>% Loss of EB.</th>
</tr>
</thead>
<tbody>
<tr>
<td>BDPU_C</td>
<td>0</td>
<td>0</td>
<td>59.08</td>
<td>--</td>
<td>369</td>
<td>--</td>
</tr>
<tr>
<td>BDPU15D</td>
<td>15</td>
<td>19.09</td>
<td>8.74</td>
<td>85.20</td>
<td>14.5</td>
<td>96.07</td>
</tr>
<tr>
<td>BDPU30D</td>
<td>30</td>
<td>21.74</td>
<td>7.20</td>
<td>87.81</td>
<td>10.7</td>
<td>97.10</td>
</tr>
<tr>
<td>BDPU60D</td>
<td>60</td>
<td>27.77</td>
<td>3.54</td>
<td>94.00</td>
<td>6.4</td>
<td>98.26</td>
</tr>
<tr>
<td>BDPU120D</td>
<td>120</td>
<td>48.15</td>
<td>2.32</td>
<td>96.07</td>
<td>5.2</td>
<td>98.59</td>
</tr>
<tr>
<td>BDPU180D</td>
<td>180</td>
<td>62.36</td>
<td>1.06</td>
<td>98.20</td>
<td>3.3</td>
<td>99.10</td>
</tr>
</tbody>
</table>
polyester urethanes synthesized in this investigation. The systematic bacterial degradation of the polyester urethane films was carried out in *Pseudomonas aeruginosa* for maximum 30 days in BOD incubator shaker. The results of degradation at different temperatures in terms of weight loss of the polymers are presented in Table 2 and Fig. 1. The results of changes in tensile strength and elongation at break of the polyester urethane samples with the progress of degradation are presented in Table 3. As in the case of soil burial degradation, each of the degraded polymer films was checked for transparency and brittleness at various stages of the test. The degraded films became brittle and non-transparent. However, as before, the gradual development of physical embrittlement of the polymer films is indicative of strong bacterial attack. Figure 1 shows the percentage weight loss of the polymer films as a function of degradation time at different temperatures. After 30 days of exposure of the polyurethane films to cultured *Pseudomonas aeruginosa* around 33-36% degradation in terms of weight loss has been observed as compared to around 22% degradation in 30 days and 62% degradation in 180 days under soil burial condition. These results indicate a stronger effect of cultured microorganism over that of the soil microorganisms. It is also seen from Table 2 and Fig. 1 that although the weight loss of the polyurethane film is little more at 37°C compared to that at 15 and 5°C but the change in weight loss is not much pronounced by changing the bacterial degradation temperature from 5 to 37°C. However, the slight increase in degradation at 37°C may be attributed to the higher growth of bacteria at this temperature (Fig. 1). *Pseudomonas aeruginosa* releases esterase enzyme, which can degrade ester bond to generate acid and alcohol[17,21]. The probable degradation reactions of the lactic acid and polyethylene glycol based polyester urethane are

![Figure 1](image1)

**Fig. 1—Degradation of lactic acid and PEG400 based polyester urethane in terms of weight loss by *Pseudomonas aeruginosa* at different temperatures.**

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**Table 2—Weight losses of lactic acid and PEG400 based polyester urethanes during degradation by cultured *Pseudomonas aeruginosa* at different temperatures**

<table>
<thead>
<tr>
<th>Sample</th>
<th>Degradation time (days)</th>
<th>Degradation in absence of bacteria (%)</th>
<th>Degradation (%) in presence of bacteria at 5°C</th>
<th>Degradation (%) in presence of bacteria at 15°C</th>
<th>Degradation (%) in presence of bacteria at 37°C</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Total</td>
<td>Actual</td>
<td>Total</td>
<td>Actual</td>
</tr>
<tr>
<td>BDPU_{P1}</td>
<td>1</td>
<td>1.5</td>
<td>23.1</td>
<td>21.6</td>
<td>23.3</td>
</tr>
<tr>
<td>BDPU_{P2}</td>
<td>7</td>
<td>1.9</td>
<td>26.3</td>
<td>24.4</td>
<td>27.0</td>
</tr>
<tr>
<td>BDPU_{P3}</td>
<td>14</td>
<td>2.1</td>
<td>29.3</td>
<td>27.2</td>
<td>30.0</td>
</tr>
<tr>
<td>BDPU_{P4}</td>
<td>21</td>
<td>2.3</td>
<td>32.2</td>
<td>29.9</td>
<td>32.8</td>
</tr>
<tr>
<td>BDPU_{P5}</td>
<td>30</td>
<td>2.3</td>
<td>35.9</td>
<td>33.6</td>
<td>36.5</td>
</tr>
</tbody>
</table>

**Table 3—Change of tensile strength and ultimate elongation of lactic acid and PEG400 based polyester urethanes during degradation by cultured *Pseudomonas aeruginosa* at different temperatures**

<table>
<thead>
<tr>
<th>Sample</th>
<th>Degradation time (days)</th>
<th>Tensile strength (MPa) after degradation at 5°C</th>
<th>Tensile strength (MPa) after degradation at 15°C</th>
<th>Tensile strength (MPa) after degradation at 37°C</th>
<th>Elongation at break (%) after degradation at 5°C</th>
<th>Elongation at break (%) after degradation at 15°C</th>
<th>Elongation at break (%) after degradation at 37°C</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>T.S. Loss (%)</td>
<td>T.S. Loss (%)</td>
<td>T.S. Loss (%)</td>
<td>T.S. Loss (%)</td>
<td>T.S. Loss (%)</td>
<td>T.S. Loss (%)</td>
</tr>
<tr>
<td>BDPU_{C}</td>
<td>0</td>
<td>59.1</td>
<td>--</td>
<td>59.1</td>
<td>--</td>
<td>369.0</td>
<td>--</td>
</tr>
<tr>
<td>BDPU_{P1}</td>
<td>1</td>
<td>65.3</td>
<td>65.3</td>
<td>70.4</td>
<td>15.9</td>
<td>73.1</td>
<td>55.7</td>
</tr>
<tr>
<td>BDPU_{P2}</td>
<td>7</td>
<td>69.2</td>
<td>14.1</td>
<td>76.1</td>
<td>12.6</td>
<td>78.7</td>
<td>39.9</td>
</tr>
<tr>
<td>BDPU_{P3}</td>
<td>14</td>
<td>75.1</td>
<td>11.2</td>
<td>81.0</td>
<td>9.2</td>
<td>84.4</td>
<td>20.3</td>
</tr>
<tr>
<td>BDPU_{P4}</td>
<td>21</td>
<td>80.7</td>
<td>9.2</td>
<td>84.4</td>
<td>7.1</td>
<td>88.0</td>
<td>14.3</td>
</tr>
<tr>
<td>BDPU_{P5}</td>
<td>30</td>
<td>85.8</td>
<td>6.8</td>
<td>88.5</td>
<td>4.9</td>
<td>91.7</td>
<td>11.1</td>
</tr>
</tbody>
</table>
presented in Scheme 1. Identification of degradation products of this polyester urethane by the attack of bacteria needs further investigation.

In regard to the variation of tensile strength and elongation at break of the polyester urethane samples during degradation by cultured *Pseudomonas aeruginosa* at different temperatures it is seen, (Table 3) that, the tensile strength and ultimate elongation of the polyester urethane gradually decreased with increasing degradation time. Also the extent of degradation in terms of both the tensile strength and elongation at break increased with the increase of temperature. After 30 days of degradation the polymer showed around 86 to 92% loss in tensile strength and 97 to 98% loss in elongation at break. At this stage of degradation the polymer films became very weak and difficult to handle. In contrast to the observation of the small effect of temperature on the weight loss of the polyester urethane samples (Table 3) such effect is more in the decrease of tensile strength and elongation at break (Table 3). In other words, it can be said that the extent of degradation in terms of loss in tensile strength (86-92%) and elongation at break (97-98%) (Table 3) is higher compared to that in terms of weight loss (33-36%) (Table 2). The major reasons for this observation may be referred to the explanation provided in case of soil burial degradation due to the cleavage of ester and urethane bonds (Scheme 1) and the loss of physical integrity of the polyester urethane samples.

**FTIR analysis**

FTIR spectra of polyester urethane and degraded polyester urethanes (soil burial and bacterial degradation) are shown in Figs 2 and 3 respectively.

The changes in chemical structures of the polyester urethane due to biodegradation were assessed with the help of FTIR spectroscopy. The synthesized polyester urethanes contain mainly ester and urethane functional linkages in their backbone chains. During degradation of polyester urethane either in soil burial condition or in cultured *Pseudomonas aeruginosa* ester linkage and urethane linkage (–O–CO–NH–) can break to form acids and amine groups. Bands for –NH groups appeared at 3380-3274 cm⁻¹. The bands for C=O groups of the urethane/ester bonds appeared at 1700 cm⁻¹ for control (BDPU_C) and degraded polyester urethane samples (BDPU_P1, BDPU_P2, BDPU_P3, BDPU_P4, BDPU_P5). There is a peak at

![Scheme 1](image)

**Scheme 1**—Probable degradation reactions of lactic acid and polyethylene glycol based polyester urethane.

![Fig. 2](image)

**Fig. 2**—FTIR spectra of lactic acid and PEG400 based polyester urethanes before (control) and 1, 7, 14, 21 and 30 days of bacterial degradation.

![Fig. 3](image)

**Fig. 3**—Change of C=O peak intensity in FTIR spectra of lactic acid and PEG400 based polyester urethanes (a) after 15, 30, 60 and 180 days soil burial degradation, and (b) after 1, 7, 14, 21 and 30 days of bacterial degradation.
2370 cm$^{-1}$ in the degraded polymer sample. The peak at 2370 cm$^{-1}$ was absent in the control sample. This peak is due to the –O-H stretching frequency of the carboxylic acids, which has slightly shifted due to hydrogen bonding. The intensity of the peak at 1700 cm$^{-1}$ for ester linkage also gradually decreased with the progress of degradation (Figs 2 and 3). There is a peak at 3280 cm$^{-1}$ for free –NH stretching in the degraded polyester urethane sample. Therefore, the FTIR spectroscopic analysis of this polymer after soil burial and bacterial degradation indicates that the ester bond of the polyester urethane as well as urethane bonds are broken and converted to acid and amine groups showing the degradation of the polyester urethane (Scheme 1).

**Optical and scanning electron microscopy**

Optical and scanning electron micrographs of the control and degraded samples (soil burial and bacterial degradation) are shown in Figs 4 and 5. The surface of the control sample is nearly smooth and free from cracks and pits. Interestingly the degraded sample shows numerous holes and cracks on the surface, which points out that the substantial influence of bacteria on the sample has initiated the degradation. The holes and cracks have increased with the increased degradation time. As compared to the degradation features seen in optical micrographs, more clarity in degraded morphology has been observed in scanning electron micrographs. The scanning electron micrographs taken at 1500 magnifications reveal that there is gradual change in morphology of the polyester urethane films with the progress of degradation from 15 days to 180 days. While no holes or valleys are visible in the control sample (Fig. 5a), but with the progress of degradation the bulk of the film appeared to be shredded with more irregular features (Fig. 5).

**Conclusion**

Biodegradation characteristics of the synthesized polyester urethane were studied in soil burial condition as well as in cultured *Pseudomonas aeruginosa*. The soil burial and cultured bacterial degradation was monitored by weight loss and tensile properties loss of the synthesized polyester urethane. The rate of degradation of the synthesized polyester urethane in cultured bacteria (*Pseudomonas*

**Fig. 4**—Optical micrographs of lactic acid and PEG400 based polyester urethane (a) before degradation, (b) after 15 days soil burial, (c) after 1 month soil burial, and (d) after 2 months soil burial degradation.

**Fig. 5**—SEM photographs of lactic acid and PEG400 based polyester urethane (a) before degradation, (b) after 1 month soil burial, (c) after 6 months soil burial degradation, (d) after 7 days of bacterial degradation, and (e) after 30 days of bacterial degradation.
aeruginosa) is faster than that of soil burial condition. The results of soil burial and cultured bacterial degradation indicate its potentiality in agricultural use as well as use as degradable packaging films and foams.

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