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Novel PBAT-Based Biocomposites Reinforced with Bioreosorbable Phosphate Glass Microparticles

Elena Togliatti, Diego Pugliese, Alberto Giubilini, Massimo Messori, Daniel Milanese, and Corrado Sciancalepore*

1. Introduction

In the last century, plastic materials have been rapidly developed and widely employed in various fields due to their peculiar properties and low costs. Unfortunately, most of these conventional plastics, such as polyethylene (PE), polypropylene (PP), and polystyrene (PS), have oil origin and their wastes cannot be biodegraded. Therefore, the increase in the production and consumption of traditional plastics results in oil consumption and serious environmental pollution. These major problems caused by conventional plastics should be solved for sustainable development in future.\(^{[1]}\)

The present work aims at the preparation and subsequent microstructural, mechanical, and dynamic-mechanical characterization of biocomposites based on poly(butylene adipate terephthalate) (PBAT), loaded with micro-particles of inorganic biodegradable phosphate glass (PG)\(^{[2]}\) at 0, 2, 10, and 40 wt\%, respectively named PBAT, PBAT+2%PG, PBAT+10%PG, and PBAT+40%PG.

The reinforcement of flexible polymeric matrices such as PBAT has the purpose of modifying and tailoring the mechanical and viscoelastic properties of the material in order to expand its application field especially in the food and agricultural packaging sector, thanks to the similarity of PBAT performance with polyethylene.

Biocomposites based on poly(butylene adipate terephthalate) (PBAT) and reinforced with micro-particles of inorganic biodegradable phosphate glass (PG) at 2, 10, and 40 wt\% are prepared and characterized from a mechanical and morphological point of view. Scanning electron microscope (SEM) images show a good dispersion of the PG micro-grains, even at high concentrations, in the PBAT matrix, resulting in homogeneous composites. Tensile and dynamic-mechanical tests, respectively, indicate that Young's and storage moduli increase with PG concentration. The reinforcement of PBAT aims at modifying and tailoring the mechanical and viscoelastic properties of the material to expand its application field especially in the food and agricultural packaging sector, thanks to the similarity of PBAT performance with polyethylene.

2. Results and Discussion

SEM images display homogeneous dispersion and distribution of the filler particles in the polymer matrix with no aggregates or

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2. Results and Discussion

SEM images display homogeneous dispersion and distribution of the filler particles in the polymer matrix with no aggregates or
phaseseparationthatwouldcauseadeteriorationofthematериал
properties(Figure1).
PGparticlesshowirregulargeometryandaregenerally
smallerthan10μminsize. As the magnification increases, no
voidsattheinterfacecanbeindicated,indicatingagoodsurfacewet-
tabilityandcompatibilityofPGparticlesbythepolymermatrix.
PBAT-PGcompositesexhibitaneffectiveincreaseofEupto
82%withincreasingthePGcontent,whileshowingareduction
ofσyupto20%,ofσbupto46%,ofεbupto57%,andofTupto
72%,assummarizedinTable1.
TheincreaseofEandthelimiteddecreaseinσywithincreas-
ingthePGcontentsuggesttheactivationofastresstransfer
mechanismacrossthePBAT-PGinterface,confirmingslight
positiveinteractionbetweenPBATandPG.[9]
εbandTcontinuouslydecreaseasamountofPGinthepoly-
ermatrixincreases,sincePGparticlesarestiffandnode-
deformable,accordingtothegeneraltrendobservedforfillerchar-
acteristicsonthepolymerproperties.[10,11]
DMAresultasafunctioftemperatureforthedifferent
compositesareshowninTable2. E′increaseswithincreasingPG
contentwithinthewholeanalyzedtemperaturerange.In par-
cular,abovetheglasstransitiontemperature(Tg), E′enhancement
canbeascribedtodedecreaseinthesegmentalmobilityofthe
polymerchains,duetothepresenceofPGmicro-particles.Dueto
thehigherstiffnessofPG,PBAT-basedcompositeshavegreater
resistanceatmacromolecularmotionsunderstressconditionsif
comparedwithunfilledpolymer.[12]
Tgismidentifiedasthetemperaturecorrespondingtothepoint
ofthetanδcurve,obtainedbytheE′/E″ratio. The PGaddition
doesnotsignificantlychangeTgvalueofpristinePBAT.
Averysimilartrendwasobservedinotherbio-compos-
itesystemsreinforcedwithnaturalfibers,suggestingare-
strictedinteractionbetweenfillerandpolymermatrix,asalready
observed.[13,14]

3. Conclusion
PBATisconsideredastheonemostpromisingbiodegradable
polymersandthisworkdemonstratesthesuccessfulrealizationof
biodegradablePBAT-basedcompositematerialsreinforcedby
PGmicro-particles.
AccordingtoSEMimagesofthespecimens,thefillerpar-
ticlesarefinelydispersedandhomogeneouslydistributedwithin
thepolymermatrix,evenatthehighestconcentration,without
agglomeratesformation.
Theresultsofthetensiletestsrevealaneffectiveincreasein
thestiffnessofthecompositescomparedtothepurepolymer,at
theexpenseofstrengthandelongationatbreakandtoughness.
DMAcharacteristicsofthecompositesseeanincreaseinthe
storagemodulusasthePGconcentrationincreases,whilethe
glasstransitiontemperatureremainssubstantiallyconstant.
The developed materials prove to be valid biodegradable and
eco-friendlyalternatives to traditional thermoplastic polymers,
suchasPE, and can be applied in many fields, especially in pack-
ageandmulchfilmapplications.
Table 2. Dynamic-mechanical properties of PBAT-PG composites.

<table>
<thead>
<tr>
<th>Sample</th>
<th>$E'(−40°C)$ [MPa]</th>
<th>$E'(10°C)$ [MPa]</th>
<th>$E'(20°C)$ [MPa]</th>
<th>$E'(40°C)$ [MPa]</th>
<th>$T_g$ [°C]</th>
</tr>
</thead>
<tbody>
<tr>
<td>PBAT</td>
<td>2800 ± 20</td>
<td>203 ± 20</td>
<td>178 ± 20</td>
<td>135 ± 20</td>
<td>−17.8 ± 0.5</td>
</tr>
<tr>
<td>PBAT+2%PG</td>
<td>2995 ± 20</td>
<td>251 ± 20</td>
<td>223 ± 20</td>
<td>181 ± 20</td>
<td>−17.4 ± 0.5</td>
</tr>
<tr>
<td>PBAT+10%PG</td>
<td>3310 ± 20</td>
<td>284 ± 20</td>
<td>252 ± 20</td>
<td>206 ± 20</td>
<td>−16.9 ± 0.5</td>
</tr>
<tr>
<td>PBAT+40%PG</td>
<td>5350 ± 20</td>
<td>575 ± 20</td>
<td>496 ± 20</td>
<td>359 ± 20</td>
<td>−17.2 ± 0.5</td>
</tr>
</tbody>
</table>

Conflict of Interest
The authors declare no conflict of interest.

Data Availability Statement
The data that support the findings of this study are available from the corresponding author upon reasonable request.

Keywords
biopolymers, composites, phosphate glass, poly(butylene adipate terephthalate)

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