PRODUCTION AND CHARACTERIZATION OF DEGRADABLE POLYETHELENE TEREPHTHALETE USING PRO-DEGRADANT ADDITIVES, POLYLACTIC ACID AND POLYLACTIC ACID GRAFTED MALEIC ANHYDRIDE

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I hereby declare that the work in this thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at Universiti Malaysia Pahang or any other institutions.

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DEDICATION

I specially dedicate this dissertation to my beloved parents;

Mr. Chelliah and Mrs. Jagender Kaur

Beloved Siblings and Dearest Husband

For their continuous support, guidance and believe in me.

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ABSTRAK

Keprihatinan terhadap alam sekitar yang disebabkan oleh penularan penggunaan bahan plastik sintetik seperti Polietilena tereftalat (PET) telah mewujudkan keperluan untuk pembangunan bahan plastik biodegradasi, terutamanya dalam sektor pembungkusan. Sebagai usaha untuk menggalakkan degradasi, campuran pro-degradasi (CS), asid poli lacktic gred botol (PLA) dan agen penserasi (PLA-g-MA) dengan polietilena terephthalate (PET) telah disediakan untuk mengkaji sifat-sifat dan tahap degradasi campuran tersebut. Komposit PET / CS dan campuran PET / PLA dengan dan tanpa agen penserasi disediakan menggunakan teknik penyemperitan dan pengacuan suntikan. Aditif CS dicampurkan dengan PET pada komposisi 0.25, 0.5, 0.75 dan 1 pph masing-masing. Dalam kajian ini, sebanyak 5, 10 dan 15% gred botol PLA dicampurkan dengan PET. PET yang dicampurkan dengan 15% gred botol PLA diserasikan menggunakan komposisi PLA-g-MA sebanyak 2, 4, 6 dan 8 wt %. Campuran polimer yang disediakan dicirikan melalui sifat mekanik (kekuatan tegangan tensil dan fleksural) dan ciri-ciri terma (TGA dan DSC). Kajian tahap degradasi dijalankan menggunakan kaedah pengoksidaan terma dan luluhawa dalam ruang UV. Analisa spektroskopi infra merah (FTIR) dan pengimbasan mikroskop elektron (SEM) telah dijalankan untuk mengkaji perubahan struktur molekul dan morfologi permukaan, sementara tahap degradasi diukur melalui index karbonil. Keputusan menunjukkan bahawa, 0.25CS mencatatkan TS, TM, FS dan FM yang tertinggin berbanding PET tulen. Ini menunjukkan penambahan CS hingga 0.25 pph membantu menguatkan ikatan komposit PET/CS, sekaligus mewujudkan fasa berterusan. Keputusan termal menunjukkan peningkatan kandungan CS dalam PET mengurangkan kestabilan haba PET, manakala entalpi dan penghabuluran sampel komposit berkurangan dengan peningkatan kandungan aditif CS dari 0.25 kepada 1 pph dalam PET. Kajian degradasi menggunakan analisa spektroskopi menunjukkan pertumbuhan intensity yang tidak sekata di sekitar kawasan karbonil sepanjang pendedahan kepada haba kecuali untuk sampel komposit 0.25CS. Walau bagaimanapun, bacaan CI yang rendah (kurang daripada 2.6) menafsirkan tiada kesan degradasi terhadap PET dengan penggabungan CS. Seterusnya, peningkatan penambahan gred botol PLA meningkatkan sifat mekanik PET. PLA15 mencapai TS, TM, FS dan FM tertinggi, masing-masing berbanding PET. Walau bagaimanapun, penambahan PLA-g-MA ke PLA15 telah mengakibatkan pengurangan TS, TM, FS dan FM. Kajian termal menunjukkan campuran PLA15 dengan dan tanpa PLA-MA telah mengalami degradasi dalam satu tahap dan tambahan gred botol PLA dan PLA-g-MA telah mengurangkan kestabilan terma PET. Bagi kajian degradasi, pertumbuhan intensiti pada kawasan karbonil pada campuran PLA15 selepas pendedahan haba bersama-sama dengan peningkatan CI dan penampilan permukaan menunjukkan proses degradasi. Selain itu, tambahan PLA-g-MA dalam campuran PLA15 turut menggalakan proses degradasi berlaku. Secara ringkasnya, pergabunggan gred botol PLA dengan PET meningkatkan kualiti PET dari segi ciri-ciri dan tahap degradasi.

ABSTRACT

Overwhelming environmental concern due to the usage of synthetic plastics such as polyethylene terephthalate (PET) has continuously evoke to the development of biodegradable plastic in the packaging segment. As an effort to promote degradation, pro-degradant (CS), bottle grade polylactic acid (PLA) and functionalised maleated polylactic acid (PLA-g-MA) were blended with polyethylene terephthalate (PET) to study on its properties and degradation behaviour. PET/CS composites, PET/PLA blends with and without compatibilizers were prepared using extrusion and injection molding technique. CS additives were incorporated into PET at a composition of 0.25, 0.5, 0.75 and 1 pph, respectively. In this study the polymer blend was prepared by adding bottle grade PLA composing of 5, 10 and 15 wt % with PET. PET blended with 15 wt % of bottle grade PLA (PLA15) were compatibilized using PLA-g-MA at 2, 4, 6 and 8 wt %, respectively. The formulated samples were then characterized by mechanical properties (tensile and flexural strengths) and thermal characteristics (TGA and DSC). Degradation studies were done using thermo-oxidative and accelerated weathering testing. Attenuated Total Reflectance-Fourier Transform Infrared (ATR-FTIR) spectroscopy and scanning electron microscope (SEM) analysis were performed to study on the molecular structural changes and surface morphologies, while degree of degradation of the polymeric blends were measured using Carbonyl Index. The results indicated that, 0.25CS recorded highest TS, TM, FS and FM compared to pure PET. This showed that addition of CS additives up to 0.25 pph promoted an improved strength and interfacial adhesion in the composites. Thermal studies showed that increasing CS loading from 0.25 to 1 pph reduced the thermal stability of PET, while enthalpy and crystallinity of the composites reduced with increasing CS loading amount in PET. Degradation studies revealed an uneven growth around the carbonyl region of all the samples in the FTIR spectrum upon thermal exposure except for 0.25CS composite sample. However, reduced CI reading (less than 2.6) on all the composite samples interprets absence of degradation in the samples. The increasing addition of bottle grade PLA improved mechanical properties of PET. PLA15 achieved the maximum TS, TM, FS and FM, respectively compared to PET. Nevertheless, addition of PLA-g-MA into PLA15 has resulted in reduced TS, TM, FS and FM. Thermal studies showed that PET/PLA blends with and without PLA-g-MA have undergone a single step decomposition and increasing loading effect of PLA and PLA-g-MA have reduced the thermal stability of PET favoring for degradation to take place. As for the degradation studies, growing carbonyl region of the PLA15 blend after thermal exposure along with increasing CI reading and surface appearance stipulates the degradation process. Likewise, increasing addition of PLA-g-MA in PLA15 blends was observed to promote degradation compared to a compatibilized effect in the PET/PLA blends. Conclusively, blending of bottle grade PLA with PET increases the added value of the polymeric blend with regards to its properties and susceptibility towards degradation.

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LIST OF SYMBOLS

%	Percentage
≥	More than or equal to
=	Equal
×	Multiply
±	Plus minus
˚C	Degree Celsius
s	Second
g	Gram
m	Mass
kg	Kilogram
hr	Hour
wt	Weight
N_2	Nitrogen gas
min	Minute
rpm	Revolutions per minute
phr	Parts per hundred
mL	Millilitre
kN	Kilo newton
MPa	Mega pascal
GPa	Giga Pascal
kv	Kilovolts
cm^{-1}	Reciprocal centimetre
g/cm^3	Gram per cubic centimetre
ml/min	Millilitre per minute
˚C/min	Degree Celsius per minute
J/g	Joule per gram
W/m_2	Watt per square metre
dl/g	Decilitre per gram
V	Volume
N	Normality
A.N	Acid number

G_r	Grafting of Maleic Anhydride
T_g	Transition glass temperature
T_m	Melting temperature
X_c	Degree of crystallinity
ΔH_{f°	Heat of fusion

LIST OF ABBREVIATIONS

ABS	Acrylonitrile butadiene styrene
ATR-FTIR	Attenuated Total Reflectance Fourier Transmission Infra-Red
CI	Carbonyl Index
CS	Cobalt stearate
DCP	Dicumyl peroxide
DSC	Differential Scanning Calorimetry
EB	Percentage of elongation of break
EG	Ethylene Glycol
FM	Flexural modulus
FS	Flexural strength
HDPE	High density polyethylene
IV	Intrinsic Viscosity
KOH	Potassium hydroxide
LDPE	Low density polyethylene
MA	Maleic anhydride
UV	Ultraviolet
PBAT	Poly(butylene adipate-co-terephthalate)
PBS	Polybutylene Succinate
PBSL	Poly (butylene succinate-co-L-lactate)
PF	Phenol formaldehyde
PCL	Polycaprolactone
PDLA	Poly (D-Lactide)
PDLLA	Poly(DL-Lactide)
PE	Polyethylene
PET	Poly(Ethylene terephthalate)
PET/PLA	Polyethylene terephthalate polylactic acid blends
PHA	Polyhydroxy acid
PHB	Polyhydroxyl butyrate
PLA	Poly (Lactic acid)
PLA-g-MA	Maleated Polylactic acid

PLLA	Poly (L-Lactide)
POE-g-MA	Maleated polyethylene octane
POP	Persistent organic pollutants
PP	Polypropylene
PP-g-MA	Maleated polypropylene
PS	Polystyrene
PVC	Polyvinyl chloride
ROP	Ring of polymerization
SEM	Scanning Emission Morphology
sPS-g-MA	Maleated syndiotactic polystyrene
TGA	Thermogravimetric Analysis
TM	Tensile modulus
TPS-g-MA	Maleated thermoplastic
TS	Tensile strength

REFERENCES

Abrusci, C., Pablos, J. L., Corrales, T., López-marín, J., Marín, I., & Catalina, F. (2011). International Biodeterioration & Biodegradation Biodegradation of photo-degraded mulching fi lms based on polyethylenes and stearates of calcium and iron as pro-oxidant additives. *International Biodeterioration & Biodegradation*, *65*(3), 451–459. http://doi.org/10.1016/j.ibiod.2010.10.012

Alauddin, M., Choudhury, I. A., El Baradie, M. A., & Hashmi, M. S. J. (1995). Plastics and their machining: A review. *Journal of Materials Processing Tech.*, *54*(1-4), 40–46. http://doi.org/10.1016/0924-0136(95)01917-0

Albertsson, A., Barenstedt, C., & Karlsson, S. (1994). Abiotic degradation products from enhanced environmentally degradable polyethylene. *Acta Polymer*, *45*, 97–103. http://doi.org/10.1002/actp.1994.010450207

Al-roomi, Y. M., & Hussain, K. F. (2005). Homo-oligomerization of Maleic Anhydride in Nonpolar Solvents : A Kinetic Study of Deviations from Nonlinear Behavior. *Journal of Applied Polymer Science*, *102*, 3404–3412. http://doi.org/10.1002/app.22831

Álvarez-chávez, C. R., Edwards, S., Moure-eraso, R., & Geiser, K. (2012). Sustainability of bio-based plastics : general comparative analysis and recommendations for improvement. *Journal of Cleaner Production*, *23*(11), 47–56. http://doi.org/10.1016/j.jclepro.2011.10.003

Amin, S., & Amin, M. (2011). Thermoplastic elastomeric (TPE) materials and their use in outdoor electrical insulation. *Reviews on Advanced Materials Science*, *29*(1), 15–30.

Ammala, A., Bateman, S., Dean, K., Petinakis, E., Sangwan, P., Wong, S., … Leong, K. H. (2011). *An overview of degradable and biodegradable polyolefins*. *Progress in Polymer Science* (Vol. 36). Elsevier Ltd. http://doi.org/10.1016/j.progpolymsci.2010.12.002

Andrady, A. L., Harnid, S. H., Hu, X., & Torikai, A. (1998). Effects of increased solar ultraviolet radiation on materials. *Journal of Phototchemistry and Photobiology B Biology*, *46*, 96–103.

Andrady, A. L., & Neal, M. a. (2009). Applications and societal benefits of plastics. *Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences*, *364*(1526), 1977–1984. http://doi.org/10.1098/rstb.2008.0304

Aparna, S., Purnima, D., & Adusumalli, R. . (2017). A Review On Various Compatibilizers And Its Effect On Mechanical Properties Of Compatibilized Nylon Blends. *Polymer-Plastics Technology and Engineering*, *56*, 617–634.

Auras, R., Harte, B., & Selke, S. (2004). An Overview of Polylactides as Packaging Materials. *Macromolecular Bioscience*, *4*, 835–864. http://doi.org/10.1002/mabi.200400043

Auras, R., Lim, L.-T., Selke, S. E. M., & Tsuji, H. (Eds.). (2010). *Poly(Lactic Acid): Synthesis, Structures, Properties, Processing, and Applications*. Hoboken, New Jersey: John Wiley & Sons, Inc.,. http://doi.org/10.1002/9780470649848

Avérous, L., & Pollet, E. (2012). Biodegradable Polymers. In *Environmental Silicate Nano-Biocomposites* (eds., pp. 13–39). London: Springer-Verlag. http://doi.org/10.1007/978-1-4471-4108-2

Awaja, F., & Pavel, D. (2005). Review :Recycling of PET. *European Polymer Journal*, *41*, 1453–1477. http://doi.org/10.1016/j.eurpolymj.2005.02.005

Barnes, D. K. A., Galgani, F., Thompson, R. C., Barlaz, M., Barnes, D. K. A., Galgani, F., … Barlaz, M. (2009). Accumulation and fragmentation of plastic debris in global environments. *Philosophical Transcation of The Royal Society*, *364*(1526), 1985–1998. http://doi.org/10.1098/rstb.2008.0205

Bhatia, A., Gupta, R. K., Bhattacharya, S. N., & Choi, H. J. (2007). Compatibility of Biodegradable Poly (lactic acid) (PLA) and Poly (butylene succinate) (PBS) Blends for Packaging Application Compatibility of biodegradable poly (lactic acid) (PLA) and poly (butylene succinate). *Korea-Australia Rheology Journal*, *19*(3), 125–131.

Bimestre, B. H., & Saron, C. (2012). Chain extension of poly(ethylene terephthalate) by reactive extrusion with secondary stabilizer. *Materials Research*, *15*(3), 467–472. http://doi.org/10.1590/S1516-14392012005000058

Birnin-Yauri, A., Ibrahim, N., Zainuddin, N., Abdan, K., Then, Y., & Chieng, B. (2017). Effect of Maleic Anhydride-Modified Poly(lactic acid) on the Properties of Its Hybrid Fiber Biocomposites. *Polymers*, *9*(5), 165. http://doi.org/10.3390/polym9050165

Blomfeldt, T. O. J., Olsson, R. T., Menon, M., Plackett, D., Johansson, E., & Hedenqvist, M. S. (2010). Novel Foams Based on Freeze-Dried Renewable Vital Wheat Gluten. *Macromolecular Materials and Engineering*, *295*, 796–801. http://doi.org/10.1002/mame.201000049

Bonhomme, S., Cuer, A., Delort, A., Lemaire, J., Sancelme, M., & Scott, G. (2003). Environmental biodegradation of polyethylene. *Polymer Degradation and Stability*, *81*, 441–452. http://doi.org/10.1016/S0141-3910(03)00129-0

Calcagno, C. I. W., Mariani, C. M., Teixeira, S. R., & Mauler, R. S. (2008). The role of the MMT on the morphology and mechanical properties of the PP / PET blends. *Composite Science and Technology*, *68*, 2193–2200.

http://doi.org/10.1016/j.compscitech.2008.03.012

Carlson, Nie, Narayan, & Dubois. (1999). Maleation of polylactide (PLA) by reactive extrusion. *Journal Of Applied Polymer Science*, *72*(000078961100003), 477–485. http://doi.org/papers://590F92D9-0B76-4B88-8729-9AF064BE5AC8/Paper/p2628

Carus, M., Ravenstjin, J., Baltus, W., Carrez, D., Kaeb, H., & Zepnik, S. (2013). *Market study on Bio-based Polymers in the World Capacities , Production and Applications : Status Quo and Trends towards 2020*. Germany. Retrieved from http://www.bio-based.eu/market_study/media/files/13-06-21MSBiopolymersExcerpt.pdf

Chen, H., Liu, Z., & Cebe, P. (2009). Chain confinement in electrospun nanofibers of PET with carbon nanotubes. *Polymer*, *50*(3), 872–880. http://doi.org/10.1016/j.polymer.2008.12.030

Chen, H., Pyda, M., & Cebe, P. (2009). Non-isothermal crystallization of PET / PLA blends. *Thermochimica Acta*, *492*, 61–66. http://doi.org/10.1016/j.tca.2009.04.023

Chen, R. S., Hafizuddin, M., Ghani, A., Salleh, M. N., & Ahmad, S. (2014). Influence of Blend Composition and Compatibilizer on Mechanical and Morphological Properties of Recycled HDPE / PET Blends. *Material Sciences and Applications*, (5), 943–952. http://doi.org/10.4236/msa.2014.513096

Chiellini, E., Corti, A., Antone, S. D., & Wiles, D. M. (2011). Oxo - biodegradable Polymers : Present Status and Future Perspectives. In *Handbook of Biodegradable Polymers*. (pp. 379–398). Weinheim: Wiley-VCH.

Chiellini, E., & Solaro, R. (1996). Biodegradable Polymeric Materials. *Advanced Materials*, *8*(4), 305–313.

Chiu, H., & Hsiao, Y. (2006). Compatibilization of Poly (ethylene terephthalate)/ Polypropylene Blends with Maleic Anhydride Grafted Polyethylene-Octene Elastomer. *Journal of Polymer Research*, *13*, 153–160. http://doi.org/10.1007/s10965-005-9020-z

Chow, W., Tham, W., & Seow, P. (2012). Effects of maleated-PLA compatibilizer on the properties of poly(lactic acid)/halloysite clay composites. *Journal of Thermoplastic Composite Materials*, *26*(10), 1349–1363. http://doi.org/10.1177/0892705712439569

Cichy, B. (2010). Polyolefin oxo-degradation accelerators - A new trend to promote environmental protection. *Polish Journal of Chemical Technology*, *12*(OCTOBER), 44–52. http://doi.org/10.2478/v10026-010-0049-3

Contat-Rodrigo, L. (2013). Thermal Characterization of the Oxo-Degradation of PP containing a Pro-Oxidant/Pro-Degradant Additive. *Polymer Degradation and*

Stability, *98*(2117-2124). http://doi.org/10.1016/j.polymdegradstab.2013.09.011

Cor, K., Martin, V. D., Christophe, P., & Robert, J. (1998). Strategies for compatibilization of polymer blends. *Progress in Polymer Science*, *23*(4), 707–757.

Corre, Y., Maazouz, A., Duchet, J., & Reignier, J. (2011). The Journal of Supercritical Fluids Batch foaming of chain extended PLA with supercritical CO 2 : Influence of the rheological properties and the process parameters on the cellular structure. *The Journal of Supercritical Fluids*, *58*(1), 177–188. http://doi.org/10.1016/j.supflu.2011.03.006

Deanin, R. D. (1975). Additives in Plastic. *Environmental Health Perspective*, *11*, 35–39.

Detyothin, S., Selke, S. E. M., Narayan, R., Rubino, M., & Auras, R. (2013). Reactive functionalization of poly(lactic acid), PLA: Effects of the reactive modifier, initiator and processing conditions on the final grafted maleic anhydride content and molecular weight of PLA. *Polymer Degradation and Stability*, *98*(12), 2697–2708. http://doi.org/10.1016/j.polymdegradstab.2013.10.001

Dotan, A. (2014). Biobased Thermoset. In *Handbook of Thermoset Plastics* (pp. 559–604). Elsevier Inc. http://doi.org/10.1016/B978-1-4557-3107-7.00015-4

Estudo, G. De, Química, D. De, & Ciência, D. (2015). Maleic Anhydride as a Compatibilizer and Plasticizer in TPS/PLA Blends. *Journal of the Brazilian Chemical Society*, *26*(8), 1583–1590.

Fechine, G. J. M., Rabello, M. S., Souto Maior, R. M., & Catalani, L. H. (2004). Surface characterization of photodegraded poly(ethylene terephthalate). The effect of ultraviolet absorbers. *Polymer*, *45*(7), 2303–2308. http://doi.org/10.1016/j.polymer.2004.02.003

Feldman, D. (2002). Polymer Weathering : Photo-Oxidation. *Journal of Polymers and the Environment*, *10*(4), 163–173.

Gardella, L., & Calabrese, M. (2014). PLA maleation : an easy and effective method to modify the properties of PLA / PCL immiscible blends. *Colloid and Polymer Science*, *292*, 2391–2398. http://doi.org/10.1007/s00396-014-3328-3

Gardette, M., Thérias, S., Gardette, J., Murariu, M., & Dubois, P. (2011). Photooxidation of polylactide / calcium sulphate composites. *Polymer Degradation and Stability*, *96*(4), 616–623. http://doi.org/10.1016/j.polymdegradstab.2010.12.023

Germany Trade & Invest. (2015). *Germany Trade & Invest, Industry Overview: The Plastics Industry in Germany*. Berlin.

Gewert, B., Plassmann, M. M., & Macleod, M. (2015). Environmental Science Processes

& Impacts Pathways for degradation of plastic polymers fl oating in the marine environment. *Environmental Science: Processes & Impacts*, *17*, 1513–1521. http://doi.org/10.1039/C5EM00207A

Girija, B. G., Sailaja, R. R. N., & Madras, G. (2005). Thermal degradation and mechanical properties of PET blends. *Polymer Degradation and Stability*, *90*(1), 147–153. http://doi.org/10.1016/j.polymdegradstab.2005.03.003

Glassner, D. A., Gruber, P. R., Vink, E. T. H., & Ra, K. R. (2003). Applications of life cycle assessment to NatureWorks TM polylactide (PLA) production. *Polymer Degradation and Stability*, *80*, 403–419. http://doi.org/10.1016/S0141-3910(02)00372-5

Gonzalez-Gutierrez, J., Partal, P., Garcia-Morales, M., & Gallegos, C. (2013). Bioresource Technology Development of highly-transparent protein / starch-based bioplastics. *Bioresource Technology*, *101*(6), 2007–2013. http://doi.org/10.1016/j.biortech.2009.10.025

Hauptt, R. A., & Sellers, T. (1994). Phenol-Formaldehyde Resol Resins. *Industrial and Engineering Chemistry Research*, *33*, 693–697.

Imre, B., & Pukánszky, B. (2013). Compatibilization in bio-based and biodegradable polymer blends. *European Polymer Journal*, *49*(6), 1215–1233. http://doi.org/10.1016/j.eurpolymj.2013.01.019

Islam, N. M., Othman, N., Ahmad, Z., & Ismail, H. (2010). Polymer-Plastics Technology and Engineering Effect of Pro-degradant Additives Concentration on Aging Properties of Polypropylene Films. *Polymer Plastic Technology and Engineering*, *49*, 272–278. http://doi.org/10.1080/03602550903413904

Jakubowicz, I. (2003). Evaluation of degradability of biodegradable polyethylene (PE). *Polymer Degradation and Stability*, *80*, 39–43. http://doi.org/10.1016/S0141-3910(02)00380-4

Jang, S., Yang, E. K., Jin, S. Il, Cho, Y. D., Choe, E. K., & Park, and C. R. (2012). Characterization of Thermal Degradation of Polytrimethylene Terephthalate. *Bulletin of the Korean Chemical Society*, *33*(3), 833–838.

Jansson, A., Moller, K., & Gevert, T. (2003). Degradation of post-consumer polypropylene materials exposed to simulated recycling - Mechanical properties Degradation of post-consumer polypropylene materials exposed to simulated recycling — mechanical properties. *Polymer Degradation and Stability*, *82*, 37–46. http://doi.org/10.1016/S0141-3910(03)00160-5

Jayasekara, R., Harding, I., Bowater, I., & Lonergan, G. (2005). Biodegradability of a Selected Range of Polymers and Polymer Blends and Standard Methods for Assessment of Biodegradation. *Journals of Polymer and the Environment*, *13*(3).

http://doi.org/10.1007/s10924-005-4758-2

John, J., Tang, J., Yang, Z., & Bhattacharya, M. (1996). Synthesis and Characterization of Anhydride-Functional Polycaprolactone. *Polymer Science Part A: Polymer Chemistry*, *35*(6), 1139–1148. http://doi.org/10.1002/(sici)1099-0518(19970430)35:6<1139::aid-pola17>3.0.co;2-7

John, R. P., Nampoothiri, K. M., & Pandey, A. (2006). Solid-state fermentation for L - lactic acid production from agro wastes using Lactobacillus delbrueckii. *Process Biochemistry*, *41*(4), 759–763. http://doi.org/10.1016/j.procbio.2005.09.013

Jung, K. H., Huh, M. W., Meng, W., Yuan, J., Hyun, S. H., Bae, J. S., … Kang, I. K. (2007). Preparation and Antibacterial Activity of PET/Chitosan Nanofibrous Mats Using an Electrospinning Technique. *Journal of Applied Polymer Science*, *105*, 2816–2823. http://doi.org/10.1002/app

Khoo, R. Z., Ismail, H., & Chow, W. S. (2016). Thermal and Morphological Properties of Poly (lactic acid)/ Nanocellulose Nanocomposites. *Procedia Chemistry*, *19*, 788–794. http://doi.org/10.1016/j.proche.2016.03.086

Kint, D., & Munoz-Guerra, S. (1999). Review A review on the potential biodegradability of poly (ethylene terephthalate). *Polymer International*, *48*, 346–352.

Klyosov, A. A. (2007). *Wood-Plastic Composites*. Hoboken, New Jersey: John Wiley & Sons, Inc.,.

Konduri, M. K. R., Koteswarareddy, G., Kumar, D. B. R., Reddy, B. V., & Narasu, M. L. (2011). Effect of Pro-Oxidants on Biodegradation of Polyethylene (LDPE) by Indigenous Fungal Isolate , Aspergillus oryzae. *Journal of Applied Polymer Science*, *120*, 3536–3545. http://doi.org/10.1002/app

Kyrikou, I., & Briassoulis, D. (2007). Biodegradation of Agricultural Plastic Films : A Critical Review. *Journals of Polymer and the Environment*, *15*(2), 125–150. http://doi.org/10.1007/s10924-007-0053-8

Lashgari, S., Azar, A. A., Lashgari, S., & Gezaz, S. M. (2010). Properties of Waste-Poly (Ethylene Terephthalate)/ Acrylonitrile Butadiene Styrene Blends Compatibilized With Maleated Acrylonitrile Butadiene Styrene. *Journal of Vinyl and Additive Technology*, *16*(4), 246–253. http://doi.org/10.1002/vnl

Li, H., Chen, H., Shen, Z., & Lin, S. (2002). Preparation and characterization of maleic anhydride-functionalized syndiotactic polystyrene. *Polymers*, *43*, 5455–5461.

Lim, S., Jane, J., Rajagopalan, S., & Seib, P. A. (1992). Effect of Starch Granule Size on Physical Properties of Starch-Filled Polyethylene Film+. *Biotechnology Progress*, *8*(1), 51–57.

Liu, W., Wang, Y.-J., & Sun, Z. (2003). Effects of Polyethylene-Grafted Maleic Anhydride (PE-gMA) on Thermal Properties, Morphology, and Tensile Properties of Low-Density Polyethylene (LDPE) and Corn Starch Blends. *Journal of Applied Polymer Science*, *88*, 2904–2911. http://doi.org/10.1002/app.11965

Maddah, H. A. (2016). Polypropylene as a Promising Plastic : A Review. *American Journal of Polymer Science*, *6*(1), 1–11. http://doi.org/10.5923/j.ajps.20160601.01

Madhu, G., Mandal, D. K., Bhunia, H., & Bajpai, P. K. (2016). Thermal degradation kinetics and lifetime of HDPE / PLLA / pro-oxidant blends. *Journal of Polymer Engineering*, *58*(1), 57–75. http://doi.org/10.1515/polyeng-2015-0199

Majid, R. A., Ismail, H., & Taib, R. M. (2010). The Effects of Natural Weathering on the Properties of Linear Density Polyethylene (LDPE)/ Thermoplastic ... The Effects of Natural Weathering on the Properties of Linear Density Polyethylene (LDPE)/ Thermoplastic Sago. *Polymer Plastic Technology and Engineering*, *49*(July), 1142–1149. http://doi.org/10.1080/03602559.2010.482081

Mani, R., Bhattacharya, M., & Tang, J. (1998). Functionalization of Polyesters with Maleic Anhydride. *Journal of Polymer Science ;Part A:Polymer Chemistry*, *37*, 1693–1702.

Mantia, F. P. La, Botta, L., Morreale, M., & Scaffaro, R. (2012). Effect of small amounts of poly (lactic acid) on the recycling of poly (ethylene terephthalate) bottles. *Polymer Degradation and Stability*, *97*(1), 21–24. http://doi.org/10.1016/j.polymdegradstab.2011.10.017

Mekonnen, T., Mussone, P., & Bressler, D. (2013). Progress in bio-based plastics and plasticizing modifications. *Journal of Materials Chemistry A*, (1), 13379–13398. http://doi.org/10.1039/c3ta12555f

Mello, D. De, Pezzin, H., & Amico, S. C. (2009). The effect of post-consumer PET particles on the performance of flexible polyurethane foams. *Polymer Testing*, *28*(7), 702–708. http://doi.org/10.1016/j.polymertesting.2009.05.014

Modesti, M., Lorenzetti, A., Bon, D., & Besco, S. (2005). Effect of processing conditions on morphology and mechanical properties of compatibilized polypropylene nanocomposites. *Polymer*, *46*, 10237–10245. http://doi.org/10.1016/j.polymer.2005.08.035

Mohanty, A. K., Misra, M., & Drzal, L. T. (2002). Sustainable Bio-Composites from Renewable Resources : Opportunities and Challenges in the Green Materials World. *Journal of Polymers and the Environment*, *10*, 19–26.

Muenprasat, D., Suttireungwong, S., & Tongpin, C. (2010). Functionalization of Poly (Lactic Acid) with Maleic Anhydride for Biomedical Application. *Journal of Metal, Materials and Minerals*, *20*(3), 189–192.

Nampoothiri, K. M., Nair, N. R., & John, R. P. (2010). An overview of the recent developments in polylactide (PLA) research. *Bioresource Technology*, *101*(22), 8493–8501. http://doi.org/10.1016/j.biortech.2010.05.092

NatureWorks. (2017). Ingeo Resin Naturally Advanced Materials Product Guide. *NatureWorks LLC*, 7. Retrieved from http://www.natureworksllc.com/~/media/Files/NatureWorks/Technical-Documents/One-Pagers/ingeo-resin-grades-brochure_pdf.pdf

Ohkita, T., & Lee, S. (2005). Thermal Degradation and Biodegradability of Poly (lactic acid)/ Corn Starch Biocomposites. *Journal of Applied Polymer Science*, *100*(3009-3017). http://doi.org/10.1002/app.23425

Oromiehie, A., Ebadi-Dehaghani, H., & S Mirbagheri. (2014). Chemical Modification of Polypropylene by Maleic Anhydride: Melt Grafting, Characterization and Mechanism. *International Journal of Chemical Engineering and Applications*, *5*(2), 117–122. http://doi.org/10.7763/IJCEA.2014.V5.363

Osawa, Z. (1988). Role of Metals and Metal-Deactivators in Polymer Degradation. *Polymer Degradation and Stability*, *20*, 203–236.

Pablos, J. L., Abrusci, C., Marín, I., López-marín, J., Catalina, F., Espí, E., & Corrales, T. (2010). Photodegradation of polyethylenes : Comparative effect of Fe and Ca-stearates as pro-oxidant additives. *Polymer Degradation and Stability*, *95*(10), 2057–2064. http://doi.org/10.1016/j.polymdegradstab.2010.07.003

Park, S. B., Hwang, S. Y., Moon, C. W., & Im, S. S. (2010). Plasticizer Effect of Novel PBS Ionomer in PLA / PBS Ionomer Blends. *Macromolecular Research*, *18*(5), 463–471. http://doi.org/10.1007/s13233-010-0512-2

Pavia, D. L., Lampman, M. G., Kriz, G. S., & Vyvyan, J. A. (2010). *Introduction to Spectroscopy*. (Mary Finch, Ed.) (4th editio). USA.

Peppas, N. a. (2002). *Handbook of Materials Selection*. (M. Kutz, Ed.)*Biomaterials* (Vol. 9). JOHN WILEY & SONS, INC. http://doi.org/10.1016/0142-9612(88)90055-5

Ping Qu, Yuan Gao, Guo-feng Wu, L. Z. (2010). Nanocomposites of poly(lactic acid) reinforced with cellulose nanofibrils. *BioResources*, *5*, 1811–1823.

Pires, H. M., Mendes, L. C., Piedade, C. S., Jayme, V., & Rodriguez, R. (2015). Effect of Weathering and Accelerated Photoaging on PET / PC (80 / 20 wt / wt %) Melt Extruded Blend. *Materials*, *18*(4), 763–768.

Plastic Insight. (2016). Global PET Resin Production Capacity. Retrieved March 25, 2017, from www.plasticsinsight.com/global-pet-resin-production-capacity/

Plastics Europe. (2015). *Plastics – the Facts 2015. An analysis of European plastics*

production , demand and waste data.

Pospigp, J., & Nesphek, S. (1997). Highlights in Chemistry and Physics of Polymer Stabilization. *Macromolecular Symposia*, *115*(1), 143–163.

R.B Pearson. (1982). Pvc As a Food Packaging Material. *Food Chemistry*, *8*(6), 85–96.

Ravindranath, K., & Mashelkar, R. (1990). Review Polyethylene Terephthalate-I.Chemistry, Thermodynamics and Transport Properties. *Chemical Engineering Science*, *41*(9), 2197–2214.

Reddy, M. M., Deighton, M., Gupta, R. K., Bhattacharya, S. N., & Parthasarathy, R. (2008). Biodegradation of Oxo-Biodegradable Polyethylene. *Journal of Applied Polymer Science*, *111*, 1426–1432. http://doi.org/10.1002/app

Reddy, M. M., Vivekanandhan, S., Misra, M., Bhatia, S. K., & Mohanty, A. K. (2013). Biobased plastics and bionanocomposites : Current status and future opportunities. *Progress in Polymer Science*, *38*(10-11), 1653–1689. http://doi.org/10.1016/j.progpolymsci.2013.05.006

Relpet. (2017). *PET DIVISION DUECARE MANUAL*. Retrieved from http://www.ril.com/html/business/py_relpet_pdts.html

Rogers, M. E., & Long, T. E. (2003). *Synthetic Methods in Step-Growth Polymers*. y John Wiley & Sons, Inc., Hoboken, New Jersey. http://doi.org/10.1002/0471220523.ch1

Rosemarie Downey. (2016). *Asia-Pacific: Growth Region for PET Bottles*. Retrieved from http://blog.euromonitor.com/2016/01/asia-pacific-consolidates-its-position-as-headline-global-growth-region-for-pet-bottles.html

Roy, P. K., Surekha, P., Rajagopal, C., & Choudhary, V. (2006). Comparative Effects of Cobalt Carboxylates on the Thermo-Oxidative Degradation of LDPE Films. *Journal of Applied Polymer Science*, *103*, 3758–3765. http://doi.org/10.1002/app

Roy, P. K., Surekha, P., Rajagopal, C., & Choudhary, V. (2007). Thermal degradation studies of LDPE containing cobalt stearate as pro-oxidant. *Express Polymer Letters*, *1*(4), 208–216. http://doi.org/10.3144/expresspolymlett.2007.32

Roy, P. K., Surekha, P., Rajagopal, C., Raman, R., & Choudhary, V. (2005). Study on the Degradation of Low-Density Polyethylene in the Presence of Cobalt Stearate and Benzil. *Journal of Applied Polymer Science*, *99*, 236–243. http://doi.org/10.1002/app.22464

Sam, S. T., Ismail, H., & Ahmad, Z. (2011). Effect of Cobalt Stearate on Natural Weathering of LLDPE / Soya Powder Blends Effect of Cobalt Stearate on Natural Weathering of LLDPE / Soya Powder Blends. *Polymer Plastic Technology and Engineering*, *50*, 37–41. http://doi.org/10.1080/03602559.2011.553863

Sani, N. S. A., Arsad, A., Rahmat, A. R., & Mohammad, N. N. B. (2015). Effects of Compatibilizer on Thermal and Mechanical Properties of PLA / NR Blends. *Material Science Forum*, *819*, 241–2445. http://doi.org/10.4028/www.scientific.net/MSF.819.241

Sclavons, M., Laurent, M., Devaux, J., & Carlier, V. (2005). Maleic anhydride-grafted polypropylene: FTIR study of a model polymer grafted by ene-reaction. *Polymer*, *46*(19 SPEC. ISS.), 8062–8067. http://doi.org/10.1016/j.polymer.2005.06.115

Shah, A. A., Hasan, F., Hameed, A., & Ahmed, S. (2008). Biological degradation of plastics : A comprehensive review. *Biotechnology Advances*, *26*, 246–265. http://doi.org/10.1016/j.biotechadv.2007.12.005

Sharma, N., Chang, L. P., Chu, Y. L., Ismail, H., Ishiaku, U. S., & Mohd Ishak, Z. A. (2001). Study on the effect of pro-oxidant on the thermo-oxidative degradation behaviour of sago starch filled polyethylene. *Polymer Degradation and Stability*, *71*(3), 381–393. http://doi.org/10.1016/S0141-3910(00)00189-0

Shen, L., Worrell, E., & Patel, M. K. (2010). Resources , Conservation and Recycling Environmental impact assessment of man-made cellulose fibres. *"Resources, Conservation & Recycling,"* *55*(2), 260–274. http://doi.org/10.1016/j.resconrec.2010.10.001

Shin, J., & Selke, S. E. M. (2014). Food Packaging. In S. Clark, S. Jung, & B. Lamsal (Eds.), *Food Processing: Principal and Applications* (2nd ed., pp. 249–273). John Wiley & Sons Ltd.

Sichina, W. J. (2000). *DSC as Problem Solving Tool : Measurement of Percent Crystallinity of Thermoplastics*.

Silverajah, V. S. G., Ibrahim, N. A., Zainuddin, N., Zin, W., Yunus, W., & Hassan, H. A. (2012). Mechanical, Thermal and Morphological Properties of Poly(lactic acid)/Epoxidized Palm Olein Blend. *Molecules*, (17), 11729–11747. http://doi.org/10.3390/molecules171011729

Singh, B., & Sharma, N. (2008). Mechanistic implications of plastic degradation. *Polymer Degradation and Stability*, *93*, 561–584. http://doi.org/10.1016/j.polymdegradstab.2007.11.008

Sinha, V., R.Patel, M., & Patel, J. V. (2010). Pet Waste Management by Chemical Recycling : A Review. *Journal of Polymers and the Environment*, *18*(1), 8–25. http://doi.org/10.1007/s10924-008-0106-7

Siracusa, V., Rocculi, P., Romani, S., & Dalla, M. (2008). Biodegradable polymers for food packaging : a review. *Food Science and Technology*, *19*(December), 634–643. http://doi.org/10.1016/j.tifs.2008.07.003

Smithers Pira. (2014). Demand for PET Packaging Material to reach $60 billion by 2019. Retrieved October 9, 2016, from http://www.smitherspira.com/news/2014/april/demand-for-pet-packaging-material-in-2019

Srivastava, H. P., Arthanareeswaran, G., Anantharaman, N., & Starov, V. M. (2011). Performance and properties of modi fi ed poly (vinylidene fl uoride) membranes using general purpose polystyrene (GPPS) by DIPS method. *DES*, *283*, 169–177. http://doi.org/10.1016/j.desal.2011.02.042

Standard Test Methods for Apparent Density, Bulk Factor, and Pourability of Plastic Materials. (2017). http://doi.org/10.1520/D1895-17

Tachaphiboonsap, S., & Jarukumjorn, K. (2013). Toughness and Compatibility Improvement of Thermoplastic Starch / Poly (lactic acid) Blends. *Advanced Materials Research*, *747*, 67–71. http://doi.org/10.4028/www.scientific.net/AMR.747.67

Taylor, P., & Tyler, D. R. (2007). Journal of Macromolecular Science , Part C : Polymer Reviews Mechanistic Aspects of the Effects of Stress on the Rates of Photochemical Degradation Reactions in Polymers Mechanistic Aspects of the Effects of Stress Reactions in Polymers. *Journal of Macromolecular Science*, *44*(4), 351–388. http://doi.org/10.1081/MC-200033682

Teujit, H., & Ikada, Y. (1992). Stereocomplex Formation between Enantiomeric Poly(1actic acid)s. 6. Binary Blends from Copolymers. *Macromolecules*, *25*(21), 5719–5723.

Thomas, N. L., Clarke, J., McLauchlin, A. R., & Patrick, S. G. (2012). Oxo-degradable plastics : degradation , environmental impact and recycling. In *Waste and Resource Management* (Vol. 165, pp. 133–140). ICE Publishing. Retrieved from http://www.wasteandresourcemangement.com

Thompson, R. C., Moore, C. J., Vom Saal, F. S., & Swan, S. H. (2009). Plastics, the environment and human health: current consensus and future trends. *Philosophical Transactions of The Royal Society B*, *364*(2009), 2153–2166. http://doi.org/10.1098/rstb.2009.0053

Tokiwa, Y., & Suzuki, T. (1977). Hydrolysis of Polyesters by lipases. *Nature*, *270*(5632), 76–78. http://doi.org/10.1038/270076a0

Torres-Huerta, A. M., Angel-López, D. Del, Domínguez-Crespo, M. A., Palma-Ramírez, D., Perales-Castro, M. E., & Flores-Vela, A. (2016). Morphological and mechanical properties dependence of PLA amount in PET matrix processed by single-screw extrusion. *Polymer-Plastics Technology and Engineering*, *2559*(March), 03602559.2015.1132433. http://doi.org/10.1080/03602559.2015.1132433

Torres-huerta, A. M., Palma-ramírez, D., Domínguez-crespo, M. A., & Angel-lópez, D. Del. (2014). Comparative assessment of miscibility and degradability on PET / PLA and PET / chitosan blends. *European Polymer Journal*, *61*, 285–299. http://doi.org/10.1016/j.eurpolymj.2014.10.016

Tsuji, H. (2002). Autocatalytic hydrolysis of amorphous-made polylactides : effects of l -lactide content , tacticity , and enantiomeric polymer blending. *Polymer*, *43*, 1789–1796.

Tummala, P., Liu, W., Drzal, L. T., Mohanty, A. K., & Misra, M. (2006). Influence of Plasticizers on Thermal and Mechanical Properties and Morphology of Soy-Based Bioplastics. *Industrial and Engineering Chemistry Research*, *45*, 7491–7496.

Vazquez, Y. V, Ressia, J. A., Barbosa, M. L. C. S. E., & Vallés, E. M. (2019). Prodegradant Additives Effect onto Comercial Polyolefins. *Journal of Polymers and the Environment*, *0*(0), 0. http://doi.org/10.1007/s10924-018-01364-0

Venkatachalam, S., Nayak, S. G., Labde, J. V, Gharal, P. R., Rao, K., & Kelkar, A. K. (2012). Degradation and Recyclability of Poly (Ethylene Terephthalate). In H. E.-D. M. Saleh (Ed.), *Polyester* (pp. 75–98). http://doi.org/10.5772/48612

Vidya, F., Raghul, S. S., Bhat, S. G., & Thachil, E. T. (2011). Effect of Cobalt Stearate and Vegetable Oil on UV and Biodegradation of Linear Low- density Poly (ethylene)– Poly (vinyl Alcohol) Blends. *Polymer from Renewable Resources*, *2*(4), 131–148.

Vilay, V., Mariatti, M., Ahmad, Z., Pasomsouk, K., & Todo, M. (2009a). Characterization of the Mechanical and Thermal Properties and Morphological Behavior of Biodegradable Poly (L -lactide)/ Poly (e -caprolactone) and Poly (L -lactide)/ Poly (butylene succinate- co - L -lactate) Polymeric Blends. *Journal of Applied Polymer Science*, *114*, 1784–1792. http://doi.org/10.1002/app

Vilay, V., Mariatti, M., Ahmad, Z., Pasomsouk, K., & Todo, M. (2009b). Characterization of the Mechanical and Thermal Properties and Morphological Behavior of Biodegradable Poly (L -lactide)/ Poly (e -caprolactone) and Poly (L -lactide)/ Poly (butylene succinate- co - L -lactate) Polymeric Blends. *Journal of Applied Polymer Science*, *114*(3), 1784–1792. http://doi.org/10.1002/app

Viola, N. M., Aparecida, R., Battistelle, G., Domênico, I. De, Universidade, U., & Paulista, E. (2013). Use of waste plastic and wood flour in the production of composite, 1–10.

Wang, H. U. A., Sun, X., & Seib, P. (2001). Strengthening Blends of Poly (lactic acid) and Starch with. *Journal of Applied Polymer Science*, *82*, 1761–1767. http://doi.org/10.1002/app.2018

White, C. C., Embree, E., & Patel, A. R. (2004). Development of A High Throughput

Method Incorporating Traditional Analytical Devices. *Journal of Research of the National Institute of Standards and Technology*, *109*, 465–477.

Wiles, D. M., & Scott, G. (2006). Polyolefins with controlled environmental degradability. *Polymer Degradation and Stability*, *91*, 1581–1592. http://doi.org/10.1016/j.polymdegradstab.2005.09.010

Wootthikanokkhan, J., Kasemwananimit, P., Sombatsompop, N., Kositchaiyong, A., Isarankura na Ayutthaya, A., & Kaabbuathong, N. (2012). Preparation of Modified Starch-Grafted Poly(lactic acid) and a Study on Compatibilizing Efficacy of the Copolymers in Poly(lactic acid)/Thermoplastic Starch Blends. *Journal of Applied Polymer Science*, *126*. http://doi.org/10.1002/app.36896

Wu, C. (2005). Improving Polylactide / Starch Biocomposites by Grafting Polylactide with Acrylic Acid – Characterization and Biodegradability Assessment. *Macromolecular Bioscience*, *5*, 352–361. http://doi.org/10.1002/mabi.200400159

Wu, C. (2008). Characterizing Biodegradation of PLA and PLA- g -AA / Starch Films Using a Phosphate-Solubilizing Bacillus Species. *Macromolecular Bioscience*, (8), 560–567. http://doi.org/10.1002/mabi.200700181

Xu, W., Liang, G., Zhai, H., Tang, S., Hang, G., & Pan, W.-P. (2003). Preparation and crystallization behaviour of PP/PP-g-MAH/Org-MMT nanocomposite. *European Polymer Journal*, *39*(7), 1467–1474. http://doi.org/10.1016/S0014-3057(03)00015-6

Xue-lian, X. I. A., Wen-tao, L. I. U., Xin-ying, T., & Xiang-yang, S. H. I. (2014). Degradation behaviors , thermostability and mechanical properties of poly (ethylene terephthalate)/ polylactic acid blends. *Journal of Central South University*, *21*, 1725–1732. http://doi.org/10.1007/s11771-014-2116-z

Yoshida, S., Hiraga, K., Takehana, T., Taniguchi, I., Yamaji, H., Maeda, Y., … Oda, K. (2016). *A bacterium that degrades and assimilates poly(ethylene terephthalate)* (Vol. 351).

Yousif, E., & Haddad, R. (2013). Photodegradation and photostabilization of polymers , especially polystyrene : review. *SpringerPlus*, *2*(1), 1–32.

Zeng, J.-B., Li, K.-A., & Du, A.-K. (2015). Compatibilization strategies in poly(lactic acid)-based blends. *RSC Advances*, *5*(41), 32546–32565. http://doi.org/10.1039/C5RA01655J

Zhang, J., & Sun, X. (2005). Poly(lactic acid)-based bioplastics 10. In *Biodegradable Polymers for Industrial Applications* (pp. 251–288). Elsevier. http://doi.org/10.1533/9781845690762.2.251

Zhang, J., Wang, X., Gong, J., & Gu, Z. (2004). A Study on the Biodegradability of

Polyethylene Terephthalate Fiber and Diethylene Glycol Terephthalate. *Journal of Applied Polymer Science*, *93*(3), 1089–1096. http://doi.org/10.1002/app.20556

Zhang, L., Goh, S. H., & Lee, S. Y. (1998). Miscibility and crystallization behaviour of poly(-lactide)/poly(p-vinylphenol) blends. *Polymer*, *39*(20), 4841–4847. http://doi.org/10.1016/S0032-3861(97)10167-7

Zhang, W. R., Hinder, S., Watts, J. ., Smith, R., & Lowe, C. (2011). An investigation of the effect of pigment on the degradation of a naturally weathered polyester coating. *Journal of Coatings Technology and Research*, *8*(3), 329–342. http://doi.org/10.1007/s11998-010-9305-y

Zhao, H., Cui, Z., Sun, X., Turng, L., & Peng, X. (2013). Morphology and Properties of Injection Molded Solid and Microcellular Polylactic Acid/Polyhydroxybutyrate-Valerate (PLA/ PHBV) Blends. *Industrial and Engineering Chemistry Research*, *52*, 2569–2581.

Zhu, R., Liu, H., & Zhang, J. (2012). Compatibilizing effects of maleated poly(lactic acid) (PLA) on properties of PLA/soy protein composites. *Industrial and Engineering Chemistry Research*, *51*(22), 7786–7792. http://doi.org/10.1021/ie300118x