

MECHANICAL PROPERTIES OF SELF REINFORCED POLY(LACTIC ACID) PREPARED BY COMPRESSION MOULDING

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Introduction

There are a number of successful techniques to prepare all-PP, all-PE and all-PET with a hot compaction method. A compaction method for preparing self-reinforced polymer composites was developed to promote adhesive bonding between fibres [1]. Following an initial study on all-PE composites, this hot compaction technique was successfully applied to all-PET composites [2] and PP fibres [3]. The technique requires careful temperature control during processing, since underheating will lead to insufficient wetting and interfacial adhesion, while overheating will destroy the properties of the oriented fibres [4-5]. The essence of the compaction process is to melt a fraction of the surface of each fibre under a comparatively low contact pressure to apply a substantially higher pressure for a short time to obtain consolidation of the non-woven mat. On cooling the recrystallising polymer bound the fibre together to form a fibre-polymer composite like the resin matrix in fiber-resin composites. Although the hot compaction method is an attractive method for the preparation of all-polymer composites, its main challenge is the narrow optimum processing temperature window of only a few degree. In the current study, all-PLA composites were prepared to study the temperature window of the composites with further increase of the compaction temperature to temperature within melting temperature of PLA fibre.

Experimental

Materials

Poly(lactic acid) (PLA) fibre was obtained (Far Eastern Textile Ltd, Taiwan), and formed into a non-woven mat by needle punching (Nylex Melded Fabrics Pty Ltd).

Sample Preparation

A square nonwoven fibre was cut and dried in an oven to remove moisture. The dried non woven fibre was then placed in a hot compaction press, this being pre-set so as to give required compaction temperature.

Characterization

The mechanical test was performed with modulated force thermomechanometry (mf-TM) using a Perkin-Elmer Diamond DMA (20 x 10 x 2 mm in tensile mode at 1 Hz with 10 μ m deformation, heated 30 to 190 $^{\circ}$ C at

2.0 K \cdot min $^{-1}$) and an environmental scanning electron microscopy (ESEM) was used to study the microstructure.

Results and Discussion

Figures 1, 2 and 3 illustrate the effect of temperature on the mechanical properties measured under modulated force conditions. The storage modulus, shown in Figure 1 clearly increases to 174 $^{\circ}$ C, with increasing compaction temperature, with an incremental step for compaction at 174 $^{\circ}$ C, then decreases slowly with further increase of the compaction temperature, due to further partial melting of fibres. All-PLA composites possess superior mechanical properties with the maximum storage modulus of about 7.0 GPa at compaction temperature of 174 $^{\circ}$ C.

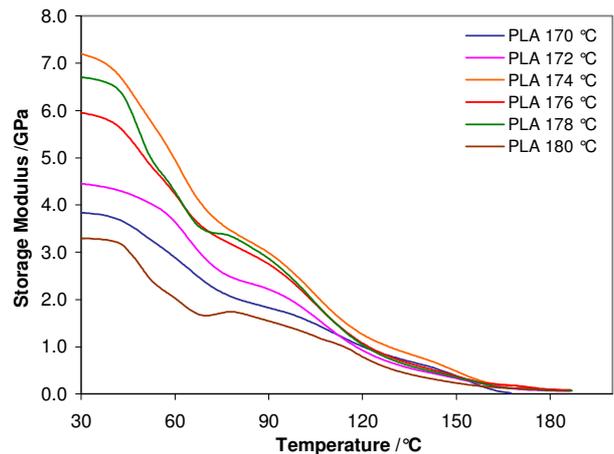


Fig. 1. Storage modulus of all-PLA composites.

The corresponding loss modulus results are shown in Figure 2. The 174 $^{\circ}$ C moulded composite had the highest loss modulus with the largest peak at T_g . Viscoelastic flow was greater when the consolidation and adhesion was increased since stress could be transferred better between fibres. The peak temperatures of the loss modulus curves were greater than the expected $T_g = 50-60$ $^{\circ}$ C. The onset temperatures corresponded better with the expected T_g . The peaks of the loss modulus curve gave T_g in the temperature range 60-70 $^{\circ}$ C.

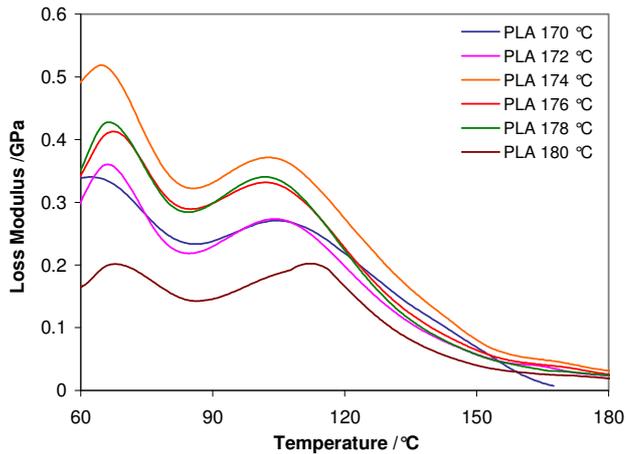


Fig. 2. Loss modulus of all-PLA composites.

Generally, the peak of loss factor or $\tan(\delta)$ are associated with the glass transition temperature T_g (β relaxation) at lower temperature and α transition temperature T_α at higher temperature. T_g indicates mobility within the amorphous regions, whereas T_α represents the onset of segmental motion within the crystalline regions [6]. Figure 3 indicates the $\tan(\delta)$ for all-PLA composites (~ 120 °C) is similar to all-PET composites [7] and 30 °C higher than that for all-PP composites (~ 90 °C) [8], which is indication of the better thermal stability of all-PLA composites.

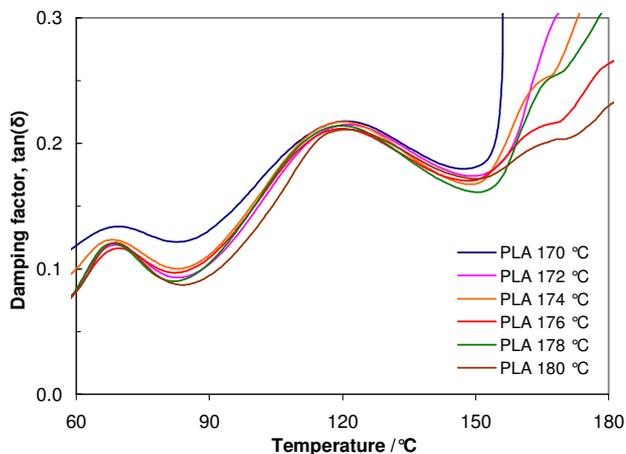


Fig. 3. Damping factor of all-PLA composites.

Figure 4 shows a cross section of all-PLA composites. The junction is completely filled with recrystallised material that has melted from the original fibre at temperature 174 °C. The contrast between the lower (170 °C) and the higher (174 °C) compaction temperatures, is quite clear, with the fibres remaining very distinct in the former case whilst in the latter, the higher temperature conditions have succeeded in apparently causing fibres to bind. Such behaviour is closely analogous to that found for hot compaction of poly(ethylene terephthalate) [1].

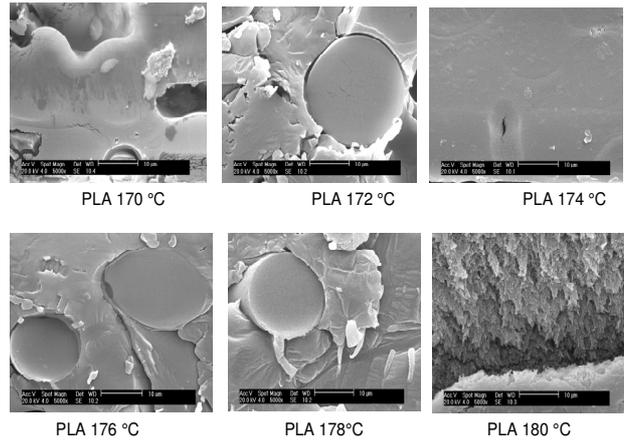


Fig. 4. ESEM images (X5000) of all-PLA composites.

Conclusion

Self reinforced poly(lactic acid) were prepared by hot compaction method with further increase of the compaction temperature to temperature within melting temperature of PLA fibre. Research found that the hot compaction method for all-PLA composites has a small temperature window of about 172 to 176 °C for optimum properties. The mechanical properties of all-PLA composites increased as the compaction temperature increased up to 174 °C. A compaction method of all-PLA suggested the temperature between 172 - 176 °C for successful compaction. SEM study shown that the gap between the fibers are filled by melted phase, and therefore consider the compaction to have been successful.

References

- [1] J. Rasburn, P. J. Hine & I. M. Ward. 1995. *Journal of Materials Science*, 30, 615-622.
- [2] J. M. Zhang & T. Peijs. 2010. *Compos: Part A. Applied Science Manufacture*, 41, 964-972.
- [3] P. J. Hine, R. H. Olley & I. M. Ward. 2008. *Compos Sci Technology*, 68, 1413-1421.
- [4] S. Bocchini, A. Frache, G. Camino & M. Claes. 2007. *European Polymer J.*, 43, 3222-3235.
- [5] A. Iwatake, M. Nogi & H. Yano. 2008. *Compos Sci Technology*, 68, 2103-2106.
- [6] Boyd RH. 1985. *Polymer*, 26(8):1123-1133.
- [7] I. M. Ward & P. J. Hine. 2004. *Polymer*, 45, 1413-1427.
- [8] Van Den Heuvel PWJ, T. Peijs & R. J. Young. 1998. *Compos Sci Technology*, 58 (6): 933-944.