Mechanical properties of PLA based films for food packaging

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Abstract. Polylactic acid (PLA) is currently the most popular source of biodegradable thermoplastic polymer adapted as a replacement for conventional petrochemical synthesized polymers. They can also be blended with Halloysite(HNT) as reinforcement nanoparticles fillers for the purpose of improving the mechanical properties. Key findings from mechanical testing suggest that preconditioning of samples in wetted environment as well as test in hydration, may affect the mechanical properties of the newly engineered materials. The purpose of the study is to investigate the different test conditions and examine how effective is HNT as a prospective carrier for antimicrobial agents i.e. Essential Oils(EOs) within the lumens for the future of food packaging applications.

Introduction

PLA is a brittle, low toughness, low glass transition temperature thermoplastic with elastic modulus of approx. 3.5GPa tensile strength (UTS) of 50MPa, elongation at break at 4-6.0% and glass transition temperature 52-60°C [1,2]. Loading of HNT at 5wt% is the optimal loading capacity demonstrated in many research works. HNT loading is said to improve the polymer's chain mobility, resulting to higher thermal stability as compared to its neat counterparts [1,2]. HNT is a cylindrical tube-like nanoparticle that is very popular because of its low cost (as compared to other nanoparticles), abundance in terms of available of supply and its physical and the chemical structure makes it very attractive for blending into the PLA matrix. According to the principle of particle reinforced composites, it follows that blending HNTs into PLA can provide reinforcement to the PLA [3]. The physical property of HNT with a hollow lumen of 5-70nm, having no surface charge on the exterior wall of this "container", makes it an attractive candidate to cater for the entrapment of antimicrobial substances such as EO within this lumen space [4]. This makes it viable as a delivery agent for slow release of antimicrobial substances onto fresh food supply to future enhance food safety and extend the shelve life of food. In the earlier stages of the research, attempts were made to encapsulate the EO in alginate beads via the electro spraying process similar to the work explored by Hia[5]. However in order to achieve nanometer size beads of size to the HNT "containers" this approach did not reap desirable results. From the experiment, I had successfully encapsulated EO within the alginate beads with an average size of 500-1000nm Fig 1(a). They were mostly irregularly cylinder shaped beads. EO was successfully encapsulated within the alginate structure shown in Fig 1(a). The alginate beads containing EO were dried and mixed into PLA solution to produce polymeric films, see Fig 1(b). The films were examined closely under the stereoscope, Fig 1(c) shows evidence that the beads were not homogeneously blended within the films. Most of the encapsulated structures were broken and this suggests that there is possible chemical and physical reaction resulting to leakage of EO during the solution casting process.

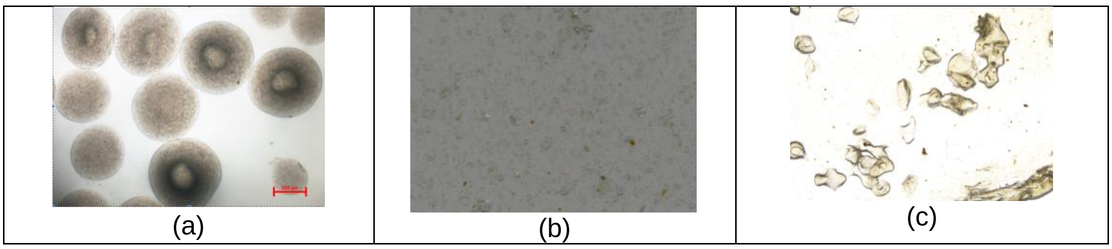

Fig 1: Images of (a) EO encapsulated in Alginate beads, (b) Alginate containing EO beads that were blended into the PLA solvent casted films, (c) PLA-HNT films containing drops of EO

In food packaging processes it is inevitable that the polymeric films would be stretched in a wetted condition, or be permanently in contact with water for a long period of time until the product is sold from the shelve. As part of investigative examination on the physical aspect of the PLA-HNT materials, it is necessary to look at the effects of hydration on these polymeric films. PLA blended with 5wt% HNT were tested on a micromechanical tester to determine its material properties. Samples were tested in dry ambient environment, in a water bath and with preconditioning of the samples as part of the test procedures conforming to ASTM D1708, ASTM D3039/D and ASTM D618 respectively. These tests are critical to determine the differences in mechanical properties of the PLA-HNT films in the different condition expected for food packaging applications.

Methods

PLA blended with 5%wt HNT were fabricated in the lab from solution casting method. The PLA-HNT films were cut into small thin samples of approximate size (L)1.8cm x (W)0.15cm. The samples were preconditioned in water at 23°C for a period of 24 hours and another set without preconditioning in water, put to test under the micromechanical tester.

Results and discussion

The test results shows that is significant difference for PLA-HNT to be preconditioned in water prior to testing where $p<0.05$. HNT is a nanoparticle that acts as reinforcement to modify the mechanical property of PLAs. The hydroxyl group in HNTs promotes hydrophilicity within the PLA composite matrix by forming more carboxlic acid end groups during the preconditioning process [6].

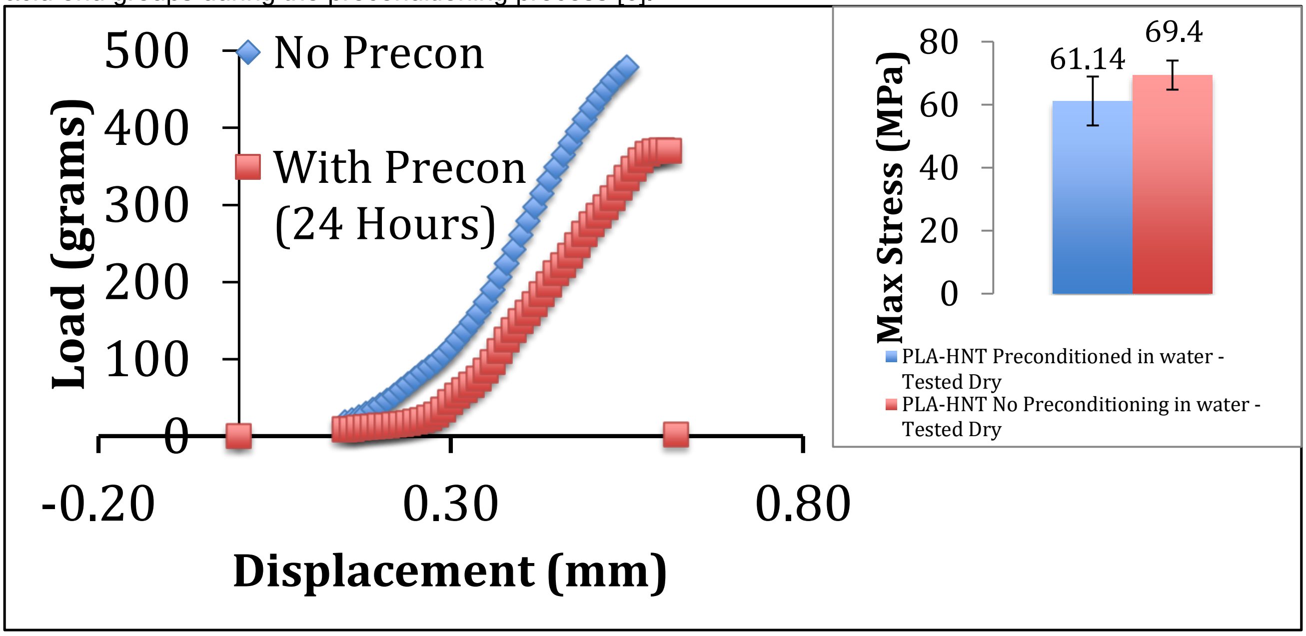

Figure 2: Load vs Displacement graph showing the difference in maximum load at which samples with preconditioning and without preconditioning fractures. Corresponding bar chart illustrating maximum stress of PLA-HNT polymer blends in the different test conditions.

Samples that were embedded in water for a period of 24 hours prior to testing, reflects lower stress tolerance. This suggests the inherent need to test with preconditioning of samples because PLAs degradation maybe expedited by hydrolysis in prolong contact with moisture in food packaging applications [6]. When samples are preconditioned in water for a period of 24 hours, the water molecules diffuses into the polymeric chains, this causes potential swelling within the PLA-HNT composites, leading to physical relaxation of molecular chains [7]. Load displacement graph in figure 2, shows a more gradual displacement slope for the samples that were preconditioned in water, compared to those samples without preconditioning. This is because the structure of the polymeric chains within the samples had become stable. Another reason would be the samples reaching the state of saturation with the preconditioning process and its material properties remained constant [7].

Blending HNTs in the polymer matrix shows evidence of improvements to the physical properties of the PLA polymers, with improvement of approximately 30% to the tensile strength. HNT as nanofillers will not compromise the biodegradability of the PLA composites [8], making it a sustainable resource for biodegradable replacements products. In food packaging industry the application and use of packaging films is widely varied. The working ambient and conditions of these films are other aspects of challenge necessary to be addressed eg high temperature in food processing process or low freezing temperature for long term storage. It is necessary to look at mechanical testing of the PLA-HNT films with the provision for these films to meet the expectation of the usage requirement. These results suggest that future testing of the films in different temperatures and conditions would possibly lead to surprising results.

Acknowledgement

I thank Dr Goh K.L for useful discussion and guidance with regard to the testing and characterization of the materials. Dr Pooria Pasbakhsh and Ms Hia from Monash University for their facility, discussion and guidance on the experimental expect of the materials and finally Workforce Development Agency (WDA) , Sensorcraft Technology (S) Pte Ltd for funding my Mphil scholarship and Newcastle University for sponsoring the conference expenses.

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