EFFECT OF FUNGI ON THE PROPERTIES OF JUTE/POLY (LACTIC ACID) COMPOSITES

Ding Ding[1], Tao Yu[2], Yan Li[3]

[1] School of Aerospace Engineering and Applied Mechanics, Tongji University, 200092, jdding@foxmail.com

[2] School of Aerospace Engineering and Applied Mechanics, Tongji University, 200092, yutao@tongji.edu.cn

[3] School of Aerospace Engineering and Applied Mechanics, Tongji University, 200092, liyan@tongji.edu.cn

Keywords: Jute, Fungi, Composites, Poly (lactic acid) PLA

ABSTRACT

Plant fiber reinforced composites as green materials are economic and environmental friendly which can be used in many areas, such as aviation, automobile, shipping etc. Jute fibers are one of the plant fibers with good sound absorption, low density, no health risks. Poly (lactic acid) (PLA) as a biomass materials can be degraded into CO_2 and H_2O. Composites with jute and PLA have shown considerable potential to replace traditional synthetic fiber reinforced composites and use in automotive components and aerospace industry. However, jute fibers as plant fibers are more easily infected with fungi than synthetic fibers such as carbon fiber or glass fiber. And the degradation rate of PLA tends to increase in the fungi environment. Therefore, it is necessary to study the effect of fungi on the properties of jute/poly (lactic acid) composites. In this paper, mechanical properties including tensile strength, bending strength and impact strength of composites were measured. Molecular weight and the morphologies were investigated by using gel permeation chromatography (GPC) and scanning electron microscope (SEM), respectively.

1 INTRODUCTION

Plant fiber reinforced polymer composites are becoming more prevalent in use due to the relatively low density and cost, acceptable specific mechanical properties, enhanced energy recovery, biodegradation and recyclable properties. This kind of materials offering such benefits as good mechanical properties, durability, reliability and lightweight lead to the growing demand for plant fiber in various industries such as aircraft, ships and automobile [1, 2].

Plant fibers such as flax, kenaf, hemp, jute and sisal etc. are made from natural-grown plants owning various advantages such as little damage during procession and reduction weight cost, less reliance on foreign oil sources, and recyclability [3, 4]. Nowadays, due to the increasing environment awareness, not only the reinforced fiber is required to be environmentally-friendly and eco-friendly, but also the matrix tend to be more pollution-free. Poly (lactic acid) (PLA) is a kind of compostable polymer with good strength and stiffness which can be derived completely from renewable resources [5, 6]. Composites compounded with natural fibers and PLA have received more attention of relative scholars.

However, both plant fiber and PLA have disadvantages. One of the greatest concerns regarding this new class of materials is their susceptibility to living organisms such as wood decaying fungi and termites which may attack them under favorable conditions and eventually lead to their degradation and loss of mechanical properties. In the meantime, degradation of PLA occurs during the using progress primarily through hydrolysis of the ester bond, and is highly dependent on temperature, moisture, microbial environment as well as thickness and geometry of the PLA article which may decline the stability of application [3, 4]. Therefore, it is significant to study the effect of fungi on such kinds of composites. A number of researches have ever been focused on the fungal resistance of plant fiber reinforced composites.

Feng. etc. studied the damage of biological agents on WPC and discovered that fungus invaded into the internal from composites surfaces [7]. Karimi. etc. reported that the mechanical properties of composites including bending strength, elastic modulus, and hardness were decreased due to the exposure to rainbow fungus [8]. Varehey and Lakes studied the variation of mechanical properties of wood fibers/thermoplastic polymer composites due to the exposure to white-rot fungi and brown-rot fungi. They found that the bending strength of composites decreased with the attack of fungi and with the increase of wood fiber percentage and exposure time, the bending strength exhibited a more considerable reduction [9]. Some researches were also found that fungi have an effect on the long-term water absorption of plant fiber reinforced composites [10].

Although there has been considerable researches devoted on the fungal resistance of the properties of plant fiber-reinforced plastic composites, there are no reports on the effect of fungi on PLA/jute composites. PLA is different from petroleum-based polymer, and the existing results are not suitable for PLA/jute composites. The objective of this work is to study the effect of fungi on the PLA/jute composites so as to find effective ways to enhance fungal resistance of this composites in the applications in future.

2 EXPERIMENTAL

2.1 Raw materials

Jute fibers were two-strand and purchased from Shanghai Qiancong Fiber Co. Ltd., China while Poly(lactic acid) (NP-4032D) were purchased from Suzhou Youli Techology Materials Co. Ltd., China. Potato sucrose agar medium(PSA) and freeze-dried powder of five kinds of fungi including aspergillus-niger, gliocladium-virens, chaetomium-globasum, aureovasidium-pullulans and penicillium -funiculosum were supplied by Shanghai Jiachu Bioengineering Co. Ltd., China.

2.2 Preparation of composites

Composites containing 10 wt% jute fibers were prepared by extrusion and injection moulding. Jute fibers and PLA were dried at 80℃ for at least 8h and then mixed in a twin-screw extruder(Nanjing Jieya Extrusion Equipment Co., Ltd., China).The PLA was melted in the first section of the compounding extruder. The jute fibers were added downstream and blended into the molten PLA. The products were cooled through water, and then cut into 2 mm. The granule dried at 80℃ for at least 8h were melted and shaped into the test specimens according to the standard by using an injection molding machine(Wuxi Haitian Mech Machinery co., Ltd.).The specimens include the specimen with the dimensions of 80mm×10mm×4mm for impact properties test and the dumbbell-shaped specimens with the length of 150mm for the tensile test.

2.3 Preparation of mould spore suspension

Five different kinds of fungi including aspergillus-niger, gliocladium-virens, chaetomium-globasum, aureovasidium-pullulans and penicillium -funiculosum were cultured for weeks on potato sucrose agar medium(PSA) and equally compounded with sterile water to prepare fungi spore suspension according to the standard of ASTM21-96 and GB/T 24128—2009. Samples were sterilized in the high pressure steam sterilization pot at 120℃ and put into culture dishes which was paved with a 2-mm thick PSA culture. And then the fungi spore suspension was sprayed onto the surfaces of the composites samples to grow for 28 days in the incubator with the temperature amid 28℃ and relative humidity around 85%. Specimens aging in the fungal environment for different days were taken to do various tests. All the instrument and drug used in this experimental were sterilized with autoclaving sterilizer or oven.

2.4 Mechanical properties testing

Samples were washed up and dried for at least 12 hours in oven at 28℃ before being taken mechanical tests. Tensile tests were performed at the rapid of 2mm/min according to the standard of GB/T 1447-2005. Bending tests were performed according to the standard of GB/T 1449-2005. Impact tests were performed according to the standard of GB/T 1043-1993. And five specimens were tested for each group.

2.5 Characterization

Apparent morphology and interior morphology were observed through visual inspection and scanning electron microscope (SEM) (VEGA TS 5136 MM, TESCAN company, Czech Republic).

Molecular weight of PLA in composites was tested through gel permeation chromatographer (GPC) to characterize the changes in molecular chains of PLA with the effect of fungi attack. Samples ranged from 10-15mg in mass were taken to dissolve in 5ml chloroform for 2 hours at room temperature to make a 3mg/ml solution.

3 RESULTS AND DISCUSSION

3.1 Composites morphology

Figure. 1 shows the surfaces of PLA/jute composites at different infected days with visual test. It can be found that most of the fungi grown normally in the culture and part of fungi attacked the surfaces. PLA on the surface of the composites degraded gradually, making jute plant fiber covered in the matrix exposed in the air.

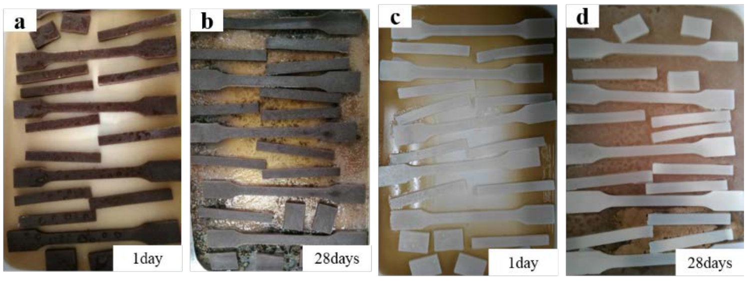

Figure 1: Visual situation of specimen infected for different days: (a) (b) Jute/PLA
(c) (d) PLA

As the Figure. 2 shown, the fracture surfaces of jute/PLA composites were observed by SEM. It can be obviously found that the interface bonding became weak after being infected with fungi from the stripped fiber status of origin samples, and holes appeared in fracture surface of infected samples. Figure.2. (d) showed the exposed jute fibers in the surface of infected samples which implied the degradation of surface PLA. Water was suitable for the growth of fungi, then it invaded the interfaces through exposed fibers and interfaces which led to different swellings degrees between fibers and PLA resulting in the weak interface bonding.

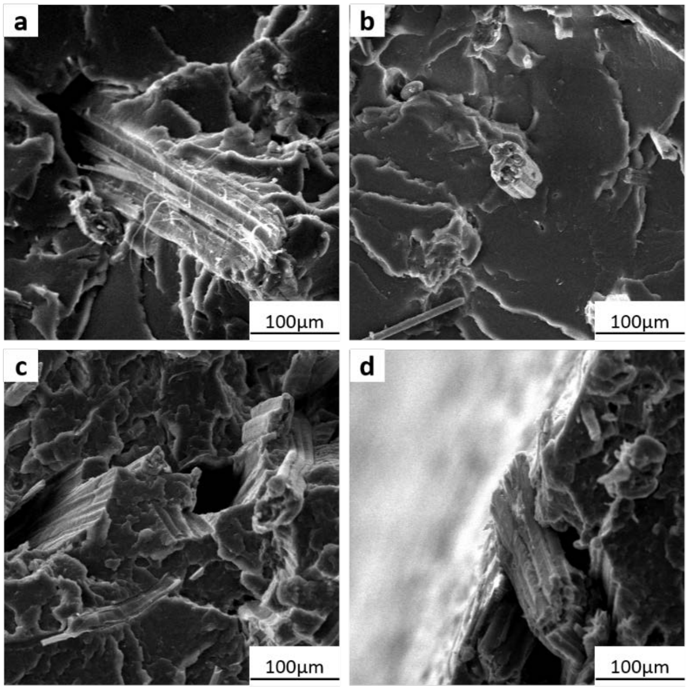

Figure 2: SEM micrographs: (a) The fiber status of origin samples (b) The interface of origin samples (c) The holes existing in infected samples (d) The exposed fiber in surface of infected samples

3.2 Mechanical properties

Tensile strength, bending strength and impact strength of original and infected samples were respectively tested to make quantitative evaluation on the effect of the fungi on composites, It can be found that the mechanical properties present a decline trend with different extent. The tensile strength of composites declined about 48.1% from 32.79MPa to 17.02MPa after 28 infected days while that of PLA declined about 12.6% from 56.51MPa to 46.41MPa. The bending strength of composites declined about 10.8% from 79.76MPa to 71.12MPa after 28 infected days while the bending strength of PLA just keep stable. The impact strength of composites declined about 29% from 28.13MPa to 19.92MPa after 28 infected days while that of PLA declined about 25.9% from 45.12MPa to 33.44MPa.Decline of mechanical properties related to the weak interface and degradation of PLA as shown in Figure 2.

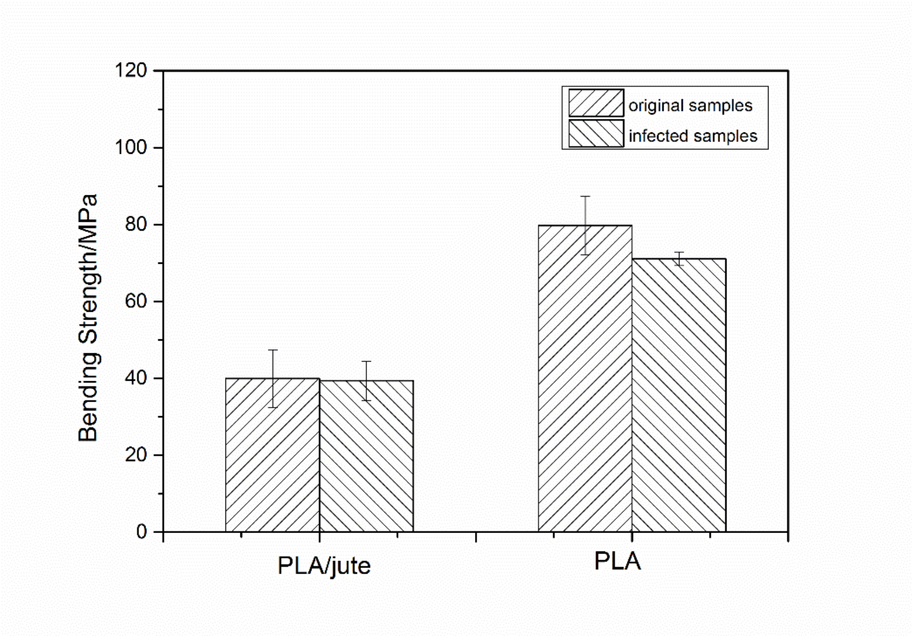

Figure 3: Bending strength of origin and infected samples

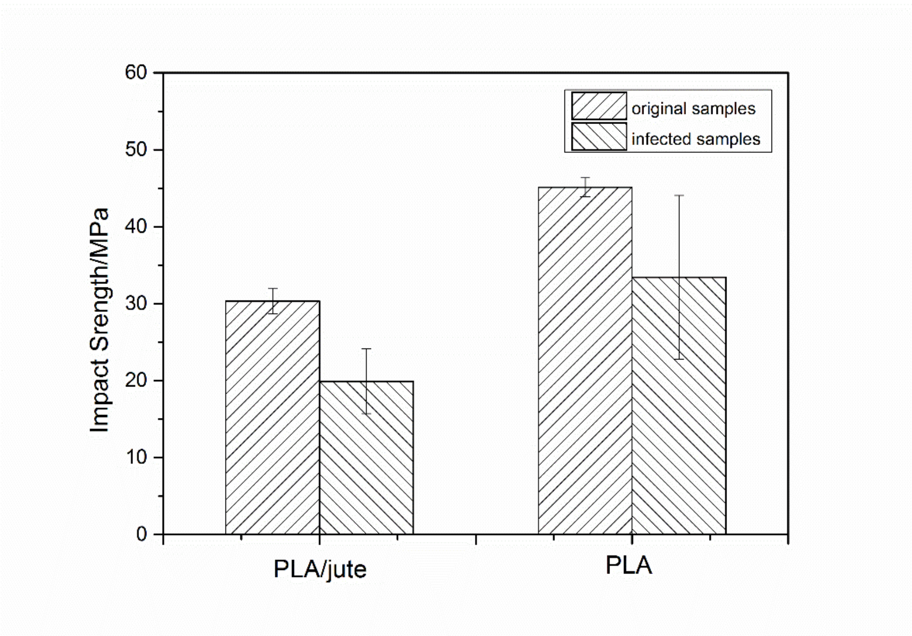

Figure 4: Impact strength of origin and infected samples

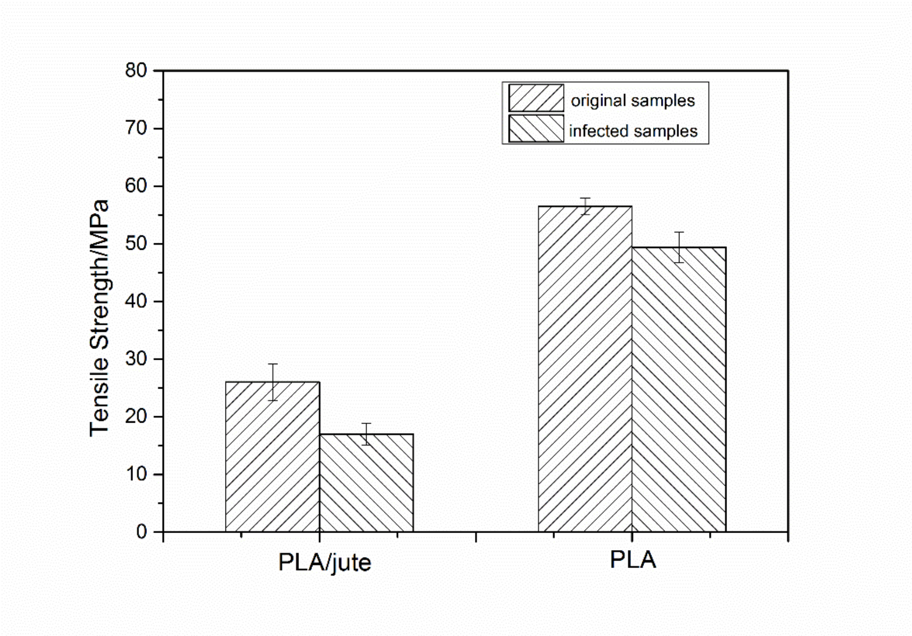

Figure 5: Tensile strength of origin and infected samples

The lower mechanical properties values of composites than PLA is for the process of high pressure steam sterilization at 120℃. PLA and jute were rearranged without fixed shape under high temperature making the weak bonding of original samples.

3.3 Molecular weight

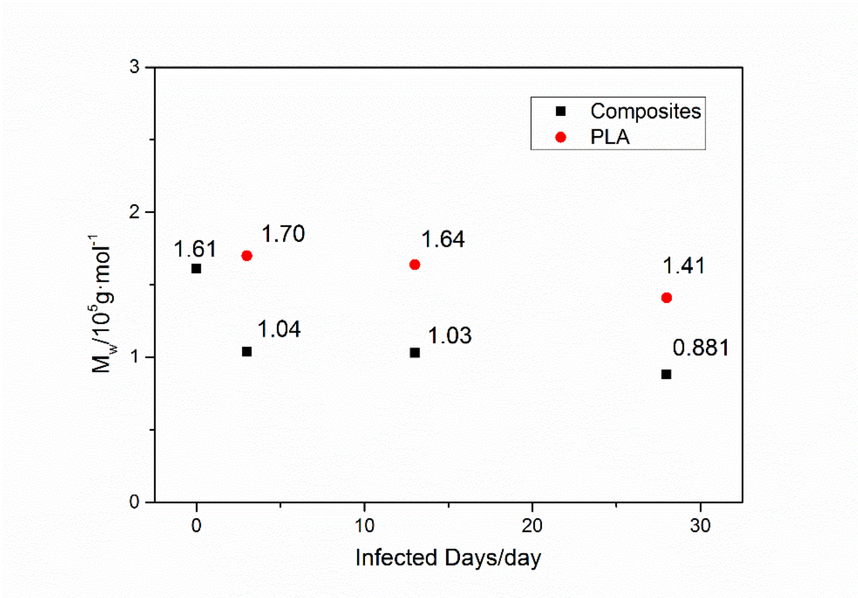

Figure 6: Molecular weight of the infected samples

Molecular weight of polymer reflects its molecular chain structure. Degradation of PLA can break the long molecular chain leading molecular weight descend. Figure6 shows the molecular weight of the PLA in composites infected for 0, 3, 13 and 28 days. It can be found that the molecular weight presented a continuous declined trend and declined about 45.3% from 1.61×105 g·mol^{-1} to 8.81×104 g·mol^{-1} after being infected for 28 days. The decline of M_w proves the degradation of PLA as shown in Figure.2 leading to the decline of mechanics properties. Increase of pure PLA M_w in original days which is corresponding to the higher value of PLA mechanical properties can be related to the pretreatment and different growth situation of fungi. The samples of PLA taken to do GPC tests were from the surface of composites which suggests attack of fungi on composites mainly happened on the surface in this experimental. Unluckily, the weight loss of composites is too tiny to be detected which suggests the degradation of PLA or fibers is finite.

4 CONCLUSION

The process of fungal effect on PLA/jute composites can be concluded as follows. Fungi grew from the culture to the samples .PLA on the surface of composites was the first to be attacked which gradually degraded under this fungi environment leading to the decline of tensile properties and bending properties. In the meantime, degradation of PLA exposed jute fibers and offered weak interfaces. And then exposed fibers and interfaces provide an access for water in the fungi growth environment to invade in which caused the enlarged interface gap between fibers and matrix, resulting in the continuous decline of the mechanical properties. In the later period of experimental, growth rate of fungi decelerated, slowing the descent of mechanics properties. Degradation of fibers were not be observed during this experimental process. And it is worth noting that high pressure steam sterilization which will cause the decline of composites mechanical properties is not a suitable way for this materials.

ACKNOWLEDGEMENTS

This work is supported by Major State Basic Research Development Program of China (973 Program) (No.2010CB631105), Natural Science Foundation of China (Nos.51103108 and 11172212) and the Fundamental Research Funds for the Central Universities.

REFERENCE

[1] Michael A. Fuqua , Shanshan Huo & Chad A. Ulven (2012) Natural Fiber Reinforced Composites, Polymer Reviews, 52:3, 259-320.

[2] Omar Faruk,* Andrzej K. Bledzki, Hans-Peter Fink, Mohini Sain. Macromol. Progress Report on Natural Fiber Reinforced Composites, Mater. Eng. 2014, 299, 9–26.

[3] Holbery, James, and Dan Houston. 2006. Natural-fiber-reinforced polymer composites in automotive applications. Jom 58 (11): 80-6.

[4] Oksman K and SainM. Wood-polymer composites. Great Abington, UK: Woodhead Publishing Ltd, 2008.

[5] Brandrup, J.; Immergut, E. H.; Grulke, E. A., Eds.; Polymer Handbook, Wiley: New York, 1999.

[6] Yan Li, K.L. Pickering. The effect of chelator and white rot fungi treatments on long hemp fibre-reinforced composites [J]. Composites Science and Technology, 2009, 6: 1265–1270.

[7] Varhey SA and Lakes PE. Wood particles size affects the decay resistance of wood fiber/thermoplastic composite. Forest Prod J 2001; 51(9): 44–49.

[8] Jing Feng, Qingshan Shi, Xiaomo Huang. The detriment of microorganism factor on the wood-plastic composites[J]. Plastic Industry, 2012,5(5):6-10.

[9] Zabihzadeh SM, Hosseini Hashemi SK, Mehregan Nikoo H, et al. Influence of fungal decay on physico-mechanical properties of a commercial extruded bagasse/PP composite. J Reinforc Plast Compos 2009; 29: 1750–1756.

[10] Maria Fiertak, Elżbieta Stanaszek-Tomal, Aleksander Kozak. The growth of fungi and their effect on the behaviour of cement-polymer composites[J]. Advances in Cement Research, 2015,27(6):340.