

Experimental Investigation of Fatigue Characteristics of Poly Lactic Acid (PLA) – A Novel Green Engineering Material

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ABSTRACT: In this paper, we investigate the fatigue characteristics of PLA and their applications in industries. PLA are exploring as an alternative solution to solve the ecological problem of plastic waste accumulation, with a major focus on packaging. PLA, due to its biodegradation ability, presents the major advantage to enter in the natural cycle implying its return to the biomass. The use of PLA in food packaging has already received significant attention and currently, PLA-based packaging and containers including bottled water, juice and yoghurt are used in Europe, Japan and North America for supermarket products. PLA based packaging materials have been regarded as safe (GRAS) which put it in a unique position for food applications. Furthermore, it has been proposed as a renewable and degradable plastic for uses in service ware, waste-composting bags, mulch films, controlled release matrices for fertilizers, pesticides, and herbicides.

KEYWORDS: Poly lactic acid, Food packaging, Eco-friendly plastics

I. INTRODUCTION

Over the past decades, the development of synthetic petroleum-based plastics has contributed to economic development and brought great benefits to human life. The annual production of plastics has been increasing worldwide, which was only 1.5 million tons dating back to 1950s and was dramatically increased to approaching 400 million tons in 2018. It is projected that global plastic production will reach 1,800 million tons per year by 2050.

Synthetic plastics have been extensively used due to their low cost, light weight, good durability and processability. However, the majority of plastic products are packaging and single used items with very short service life before disposal. Only 18% of overall plastic wastes have been recycled, and less have been incinerated. Around 70 million tons of the 90 million tons of plastic produced by human beings are accumulated in the environment and eventually break down into microplastics causing serious health concerns. Microplastic contamination has reached an alarming level in the air, water, seafood and salts. Recent research has shown overwhelming evidence that microplastics can absorb chemicals and metals in the environment which then be enriched in the food chain to endanger not only marine lives but also human beings. Plastic wastes on the sea shore and ocean surface may be removed, but debris and microplastics suspended in the ocean or at the bottom of sea floor can hardly be cleaned up.

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Bio-based plastics are being developed to replace traditional petroleum-based plastics to reduce carbon emissions (because the bio-based raw materials absorbed CO₂ from atmosphere) while bio-degradable plastics are developed to reduce plastic pollution (because they degrade much faster than traditional plastics). Poly (lactic acid) (PLA) is one of the most commercially successful bio-plastics (at least among the rigid ones) due to its good processability and mechanical properties. Its monomer, lactic acid, is derived from renewable sources, such as starch or sugar, through fermentation. The global production volume of PLA is around 190,000 tons in 2019. It has better mechanical strength, durability and transparency compared with most other bio-degradable plastics. PLA has been widely used for short life-time packaging products, such as food packaging and single used items. However, PLA can only degrade promptly in months at a high temperature (around 58°C) typically under the industrial composting conditions. Moreover, PLA has a low heat distortion temperature and poor water barrier properties compared with conventional thermoplastics.

Recently, PLA and its systems played an effective role in food processing applications, where the use of PLA in these applications was not based solely on its biodegradability because it was made from renewable resources, but PLA was being used because it worked very well and provided the excellent properties at a low cost as compared to other traditional biodegradable polymers used in medical applications. In addition, the excellent properties of PLA, including thermal properties, barrier properties, and processability, using traditional processing technologies, such as extrusion, injection moulding, compression moulding, and blow moulding, broadened its applications. The aim of this review paper is to discuss the properties for PLA and summarize the applications of PLA in food processing industries.

III. ABOUT PLA

Poly lactic Acid (PLA) is different than most thermoplastic polymers in that it is derived from renewable resources like corn starch or sugar cane. Most plastics, by contrast, are derived from the distillation and polymerization of nonrenewable petroleum reserves. Plastics that are derived from biomass (e.g. PLA) are known as bio-plastics

Poly lactic Acid is biodegradable and has characteristics similar to polypropylene (PP), polyethylene (PE), or polystyrene (PS). It can be produced from already existing manufacturing equipment (those designed and originally used for petrochemical industry plastics). This makes it relatively cost efficient to produce. Accordingly, PLA has the second largest production volume of any bio-plastic (the most common typically cited as thermoplastic starch).

There are a vast array of applications for Poly lactic Acid. Some of the most common uses include plastic films, bottles, and biodegradable medical devices (e.g. screws, pins, rods, and plates that are expected to biodegrade within 6-12 months). For more on medical device prototypes (both biodegradable and permanent) read here. PLA constricts under heat and is thereby suitable for use as a shrink wrap material. Additionally, the ease with which poly lactic Acid melts allows for some interesting applications in 3D printing.

IV. EXPERIMENTAL SETUP

4.1. 3D PRINTING

3D printing or additive manufacturing is a process of making three dimensional solid objects from a digital file. The creation of a 3D printed object is achieved using additive processes. In an additive process an object is created by laying down successive layers of material until the object is created. Each of these layers can be seen as a thinly sliced horizontal cross-section of the eventual object.

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4.2. FLUID DEPOSITION MODELING

The FDM technology works using a plastic filament or metal wire which is unwound from a coil and supplying material to an extrusion nozzle which can turn the flow on and off. The nozzle is heated to melt the material and can be moved in both horizontal and vertical directions by a numerically controlled mechanism, directly controlled by a computer-aided manufacturing (CAM) software package. The object is produced by extruding melted material to form layers as the material hardens immediately after extrusion from the nozzle. This technology is most widely used with two plastic 3D printer filament types: ABS (Acrylonitrile Butadiene Styrene) and PLA (Poly lactic acid). Though many other materials are available ranging in properties from wood fill to flexible and even conductive materials.

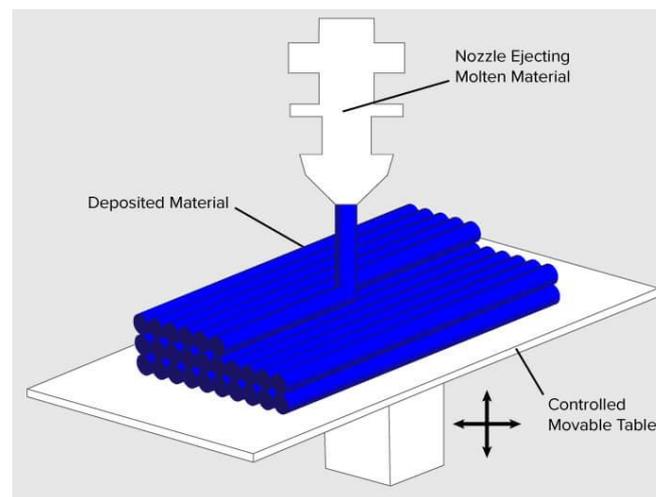


Fig 2 : FUSED DEPOSITION MODELING

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V. ANALYSIS OF FATIGUE CHARACTERISTICS

5.1. PLA BARRIER PROPERTIES:

One of the most important factors in food packaging polymers is their barrier or permeability performance against transfer of gases, water vapor, and aroma molecules. Gas permeation properties of PLA (L:D ratio 96:4) have been studied by Lehermeier and others (2001) and these values have been reported: at 30°C, N₂ permeation in PLA was 1.3 (10⁻¹⁰ cm³cm/cm²scm Hg), and the activation energy was 11.2 kJ/mol. For oxygen, the corresponding values were 3.3 (10⁻¹⁰ cm³cm/cm²scm Hg) and 11.1 kJ/mol. The values for carbon dioxide permeation were 1.2 (10⁻¹⁰ cm³cm/cm²scm Hg) and 6.1 kJ/mol. For methane, a value of 1.0 (10⁻¹⁰ cm³cm/cm²scm Hg) and an activation energy of 13.0 kJ/mol were found. The authors concluded that polymer chain branching and small changes in L:D stereochemical content have no effect on permeation properties, but film crystallinity profoundly impacted of the permeation of mentioned gases. For example, due to higher crystallinity of biaxially oriented PLA film, CH₄ permeation is 4.5 times lower than that of the other films.

5.2. SOFTWARE ANALYSIS

In the software analysis, we have tested the specimen drawing of dimensions 50 x 15 x 4 mm under ansys software under varying load conditions. The results are as follows,

5.2.1. Tensile test:

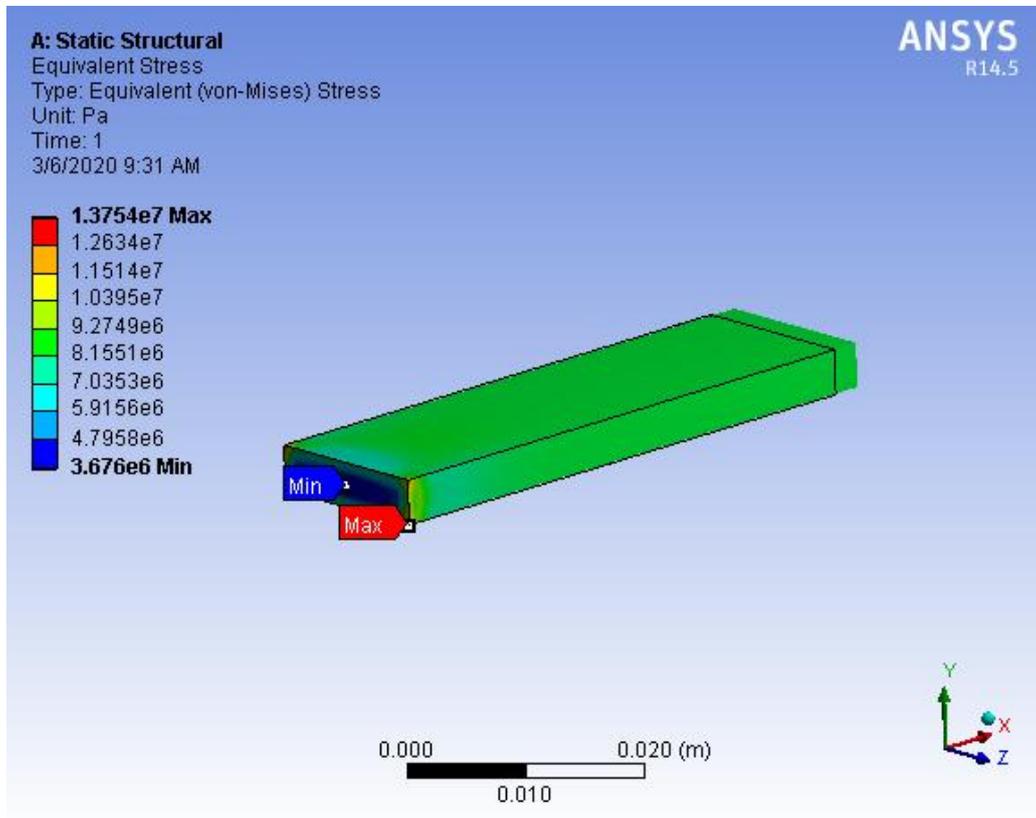


Fig 5.2.1 : Analysis of tensile test

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Table 5.2.1 : Tensile test result

PLA-TENSILE TEST	Stress Intensity	Elastic Strain Intensity	Total Deformation	Equivalent (von-Mises) Stress
Minimum	3.8109e+006 Pa	1.3516e-003 m/m	0. m	3.676e+006 Pa
Maximum	1.494e+007 Pa	5.2989e-003 m/m	1.105e-004 m	1.3754e+007 Pa

5.2.2. Compression test:

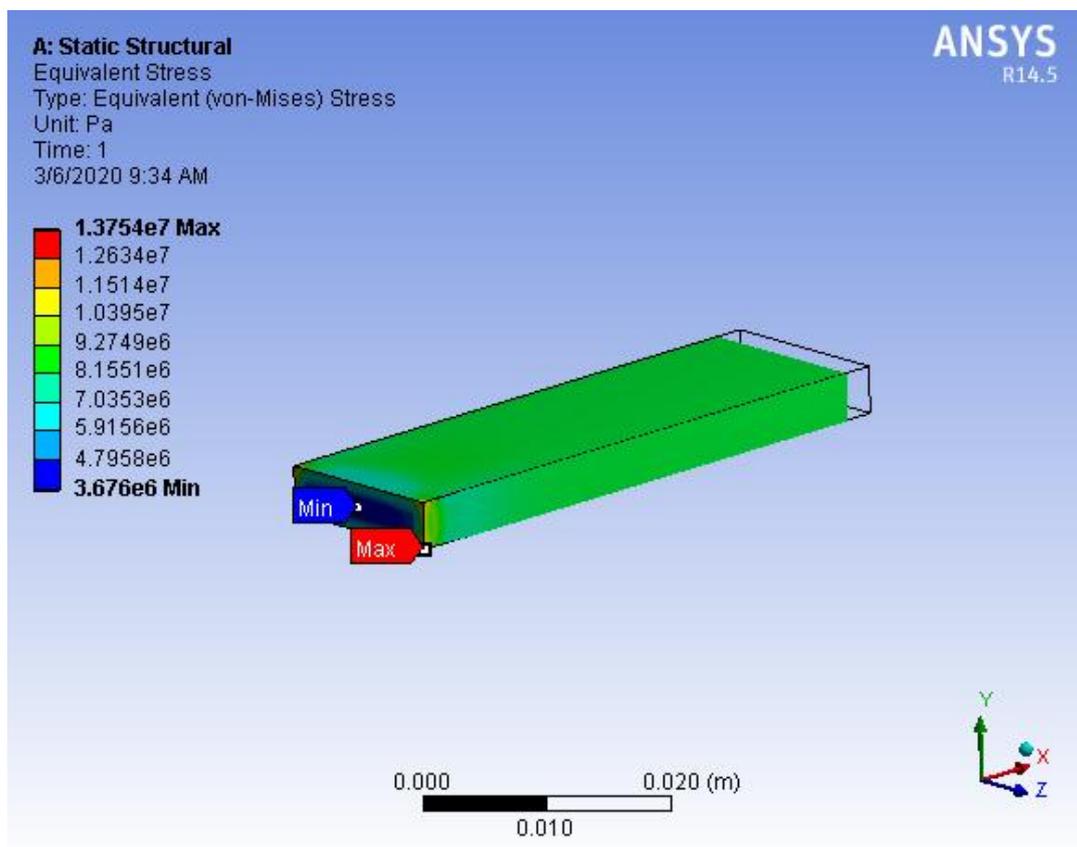


Fig 5.2.2 : Analysis of compression test

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Table 5.2.2 : Compression test result

PLA COMPRESSION TEST	Stress Intensity	Elastic Strain Intensity	Total Deformation	Equivalent (non-Mises) Stress
Minimum	3.8109e+006 Pa	1.3516e-003 m/m	0. m	3.676e+006 Pa
Maximum	1.494e+007 Pa	5.2989e-003 m/m	1.105e-004 m	1.3754e+007 Pa

5.2.3. Edge load test – 100 N:

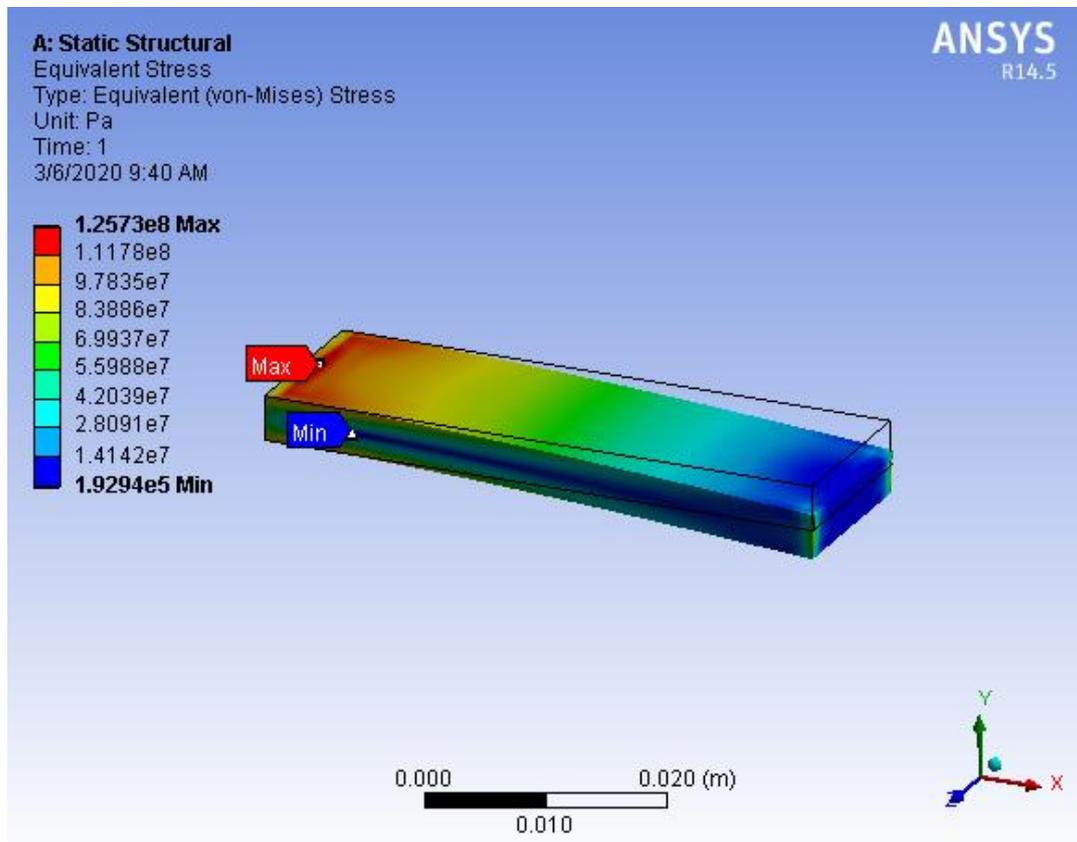


Fig 5.2.3 : Analysis of edge load test

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Table 5.2.3 : Edge load test

PLA EDGE LOAD	Stress Intensity	Elastic Strain Intensity	Total Deformation	Equivalent (von-Mises) Stress
Minimum	2.0391e+005 Pa	7.2321e-005 m/m	0. m	1.9294e+005 Pa
Maximum	1.4212e+008 Pa	5.0404e-002 m/m	1.3651e-002 m	1.2573e+008 Pa

5.2.4. Double side tensile test:

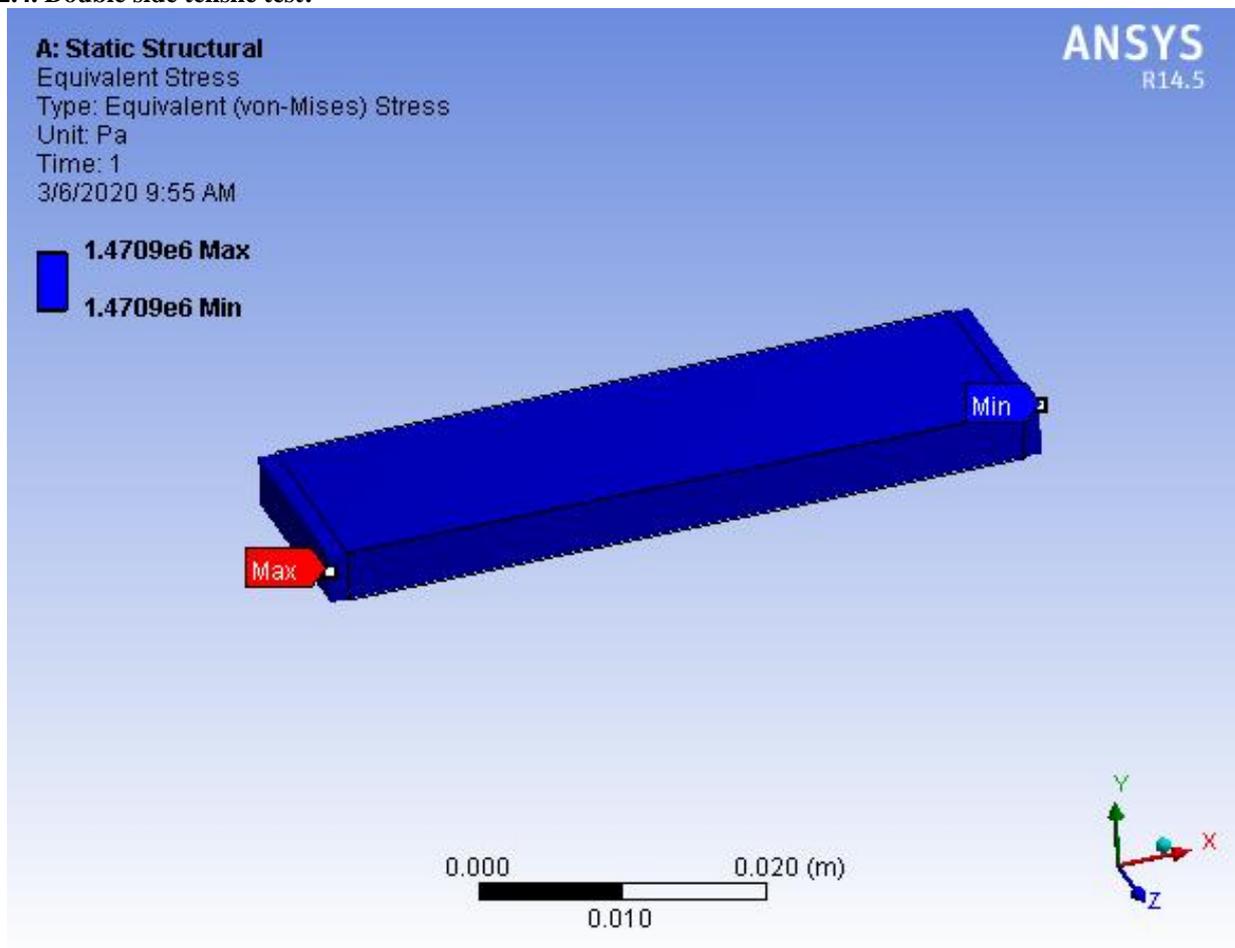


Fig 5.2.4 : Analysis of both side

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Table 5.2.4 : Double side tensile test

PLA BOTH SIDE TENSILE	Stress Intensity	Elastic Strain Intensity	Total Deformation	Equivalent (von-Mises) Stress
Minimum	1.6667e+006 Pa	5.9111e-004 m/m	2.056e-010 m	1.4709e+006 Pa
Maximum	1.6667e+006 Pa	5.9111e-004 m/m	1.0009e-005 m	1.4709e+006 Pa

VI. ADVANTAGES

- 1) The production of PLA uses 65% less energy than producing conventional plastics.
- 2) PLA generates 68% fewer greenhouse gases
- 3) When burned, it does not produce any toxic chemicals, gases, etc.

VII. APPLICATIONS

- 1) Food processing industries and food packaging.
- 2) Bone Scaffold – 3D matrix that allows and stimulates the attachment and proliferation of osteoinducible cells on its surfaces.
- 3) Surgical suture – Holding device for injury.
- 4) Clamp hell – Foldable containers for food products like pizza box.

VIII. CONCLUSION

In this study, in comparison with most other bio-degradable and bio-based plastics, PLA is by far the most important and promising one for rigid applications. The leading position of PLA is demonstrated by the current scale of the PLA industry, the number of pilot projects announced or under construction, the numerous products and applications of PLA in biodegradable and/or bio-based polymer markets, the number of polymer companies and converters involved in PLA. However, PLA exhibits poor heat stability and water barrier properties compared with some conventional thermoplastics. Tremendous efforts should be made to improve the performance of PLA via different modification methods.

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