RESEARCH ARTICLE

Investigation of the mechanical and physical properties of PLA produced by injection molding for matrix material of polymer composites

Sedef Cakir[1], Muhammed Aycicek[1], Akin Akinci[1]

[1] Sakarya University, Engineering Faculty, Metallurgical and Materials Engineering, 54187, Sakarya, Turkey

Abstract: Polymer materials are increasingly being used due to their superior properties such as light weight, low cost and corrosion resistance. The difficult destruction of highly advantageous polymers in the environment leads to environmental problems and has some disadvantages as they are obtained from exhausted sources such as oil. These problems brought new quests and biopolymers derived from renewable sources came to the forefront. In this study, mechanical and physical test results applied to PLA, which is biopolymer and their use as matrix are investigated. Mechanical tests show that PLA, which has a tensile strength of 46.88 MPa, an impact strength of 9.27 kJ/m^2 and a hardness of 79.6 Shore D, can be used as a substitute for polymers derived from petroleum-based sources.

Keywords: Polilactic acid; Injection Molding; Biopolymer; Mechanical Properties

1. Introduction

The industrial use of polymers produced from non-renewable raw materials is constantly increasing worldwide, especially in the fields of packaging and consumables, including medical uses[1]. Nowadays, commercially available polymers are obtained using about 5% natural sources such as natural gas and petroleum[2]. Studies show that the world is 50 years more gasoline and consumes about 100,000 times faster than the world can produce[3]. In addition, widely used industrial polymers such as polypropylene (PP), polystyrene (PS), polyethylene (PE) and polyethylene terephthalate (PET) do not degradable in nature for years. Therefore, it poses danger as waste to nature.

Polymer materials do not keep together properties such as strength, lightness, flexibility, toughness, impact resistance, fatigue strength and chemical resistance. For this reason, composite materials may be preferred to meet desired physical and chemical properties. In polymer composite materials, fillings and reinforcements are recommended to improve these properties. The European Union has made it mandatory for vehicles manufactured from 2015 to be manufactured from 95% recyclable materials. Thus, with the rapid growth of the automotive industry, there is a growing interest in lighter and more recyclable polymers and polymer composites to reduce energy costs.

The acquisition of petroleum-based polymers from depleted natural sources has led researchers to turn to biopolymers derived from renewable sources due to increasing environmental problems. Thus, with the increase in the use of biopolymers, the dependence on petroleum will be reduced day by day and pollution can be avoided. But biopolymers with a crisp structure need to be reinforced. In order to improve the mechanical properties of these polymers, conventional fibers such as glass, carbon fiber, and natural vegetable fibers such as bamboo, silk, linen, hemp can be used[2,3]. When a biodegradable material is obtained completely from renewable resources we may call it a green polymeric material[4]. It has been the focus of interest by many researchers and many works has been done on this area. Ar-mentano *et al* biopolymers; "Biodegradable polymers that can be separated into simple molecules such as carbon

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carbon dioxide and water by the enzymatic reaction carried out by microorganisms in the natural environment"[2]. Renewable polymeric materials offer an answer to the sustainable development of economically and ecologically attractive Technologies[4].

The concept of using bio-based plastics as reinforced matrices for biocomposites is gaining more and more approval day by day. The developments in emerging biobased plastics are spectacular from a technological point of view and mirror their rapid growth in the market place. The average annual growth rate globally was 38% from 2003 to 2007. In the same period, the annual growth rate was as high as 48% in Europe. The worldwide capacity of bio-based plastics is expected to increase from 0.36 million metric ton (2007) to 2.33 million metric ton by 2013 and to 3.45 million metric ton in 2020[5].

The repeating units are polylactic acid (PLA) formed of lactic acid, a polymer which enters the group of aliphatic polyesters. One of the most important features is that it is a biodegradable thermoplastic polymer produced from vegetable sources rich in starch such as corn, sugar cane and wheat[2]. PLA, which is a biocompatible polymer, generally obtained by polymerizing corn starch and lactic acid monomer, is the most commercially available raw material[3]. PLA is a transparent substance whose molecular weight and chemical composition can be changed by changes in its composition. Polymers obtained by low-level polymerization are used in controlled release applications and in the production of degradable films. It is believed that all these properties of PLA can replace petroleum derived plastics[6].

The high molecular weight PLA lactide ring is polymerized into PLA by open polymerization[7]. Various PLA and PLA copolymers can be obtained depending on the ratio of PLA, monomer (L or D) having L and D isomers and on the stereo chemical structure. The final properties of the produced PLA are highly dependent on the ratio of lactic acid D and L forms[8]. Commercial PLA is a linear homopolymer rather than a copolymer of poly-L-lactic acid (PLLA) and poly-D-lactic acid (PDLA). In some applications, a mixture of the homopolymer synthesized from the D and L isomers is also used (PDLLA)[1]. PLA; good strength properties are rather important commercially in terms of film transparency, biodegradability, biocompatibility and availability from renewable sources. Changes in the morphology and crystallinity of PLA copolymers may be characteristically different between glass-like materials and rubber materials, resulting in a significant change in mechanical properties. In general, these properties of PLA (e.g. tensile strength) are highly dependent on the molecular weight[9]. L poly-L-lactic acid (PLLA) synthesized from lactic acid is semi-crystalline. Poly-D-lactic acid (PDLA) synthesized from D lactic acid is crystalline. Synthesized from two monomeric compounds are poly-D-L-lactic acid (PDLLA) is amorphous[2].

Some physical and chemical properties of PLA resemble those of polymer materials such as PS (polystyrene), PP (polypropylene) and PET (polyethylene terephthalate). The similarity in properties allows the use of polylactic acid instead of PP, PET and PS in these areas[3]. Table 1 shows some properties of PLA and conventional polymers. When the table is examined it is seen that they show close features.

Properties	**PLA (Eco-PLA)**	**PS**	**LDPE**	**PP**
Density (g/cm^3)	1.21	1.04-1.09	0.92	0.90
Melting Temperature (^{o}C)	177-180	—	124	164
Breaking Stress (MPa)	45	35-64	8-10	34
Tensile Module (MPa)	2800	2800-3500	100-200	—

Elongation at Break (%)	3	1-2.5	150-600	12

Table 1. Properties of some conventional polymers and biodegradable polymers[10]

2. Materials and Methods

In this study, PLA + material supplied from Esun company of Chinese origin was used. The PLA has a density of 1.24 g/cm^3 and a melt flow index of 190°C with an EAI of 5 under a load of 1.16 kg. Firstly PLA was dried in the oven at 80ºC and then production was carried out by injection method at 210ºC.

Hardness test was carried out in accordance with the ASTM D2240 standard. For the thermoplastics, hardness test was applied to 5 samples at a thickness of 6 mm at a temperature of 25ºC using Shore D scale which is preferred.

Impact test was performed to determine the amount of energy absorbed by the material during fracture. Izod notch-free impact tests were applied to the Alarge brand device in accordance with the ISO 180 standard using 5.5 J hammer for 5 samples with dimensions of 3x12x64 mm for impact testing.

The tensile strength, elastic modulus and percent elongation were determined by applying tensile tests on three samples manufactured in accordance with the standards in Instron tensile test device using ASTM D638 standard.

In order to determine the adhesive abrasion rate of the material, a wear test was performed on the pin on disk in accordance with ASTM G99-05 standard. It was realized in the device belonging to Çetinkaya Company. In each trial, both the sample and the disc were cleaned with ethyl alcohol, taking note of the initial and final weights of the samples. The experimental conditions are listed in Table 2.

Parameters	**Conditions**
Applied Loads (N)	2, 5 ve 10
Shear Rates (m/s)	0.5, 1 ve 1.5
Temperature (ºC)	25
Humidity (% RH)	80
Sliding Distance (m)	1000

Table 2. Adhesive wear parameters

3. Experimental Results and Discussions

The data of Shore D hardness test applied to PLA are given in Table 3 and Figure 1. Looking at the average result of 5 test samples, 79.6 Shore D appears. Likewise, Nina et al.[11] reported that the hardness of pure PLA was 80 Shore D in their work on cellulose-reinforced PLA.

Hardness Value (Shore D)
79
80
80
80
79
Avg. Hardness: 79,6

Table 3. Hardness test results

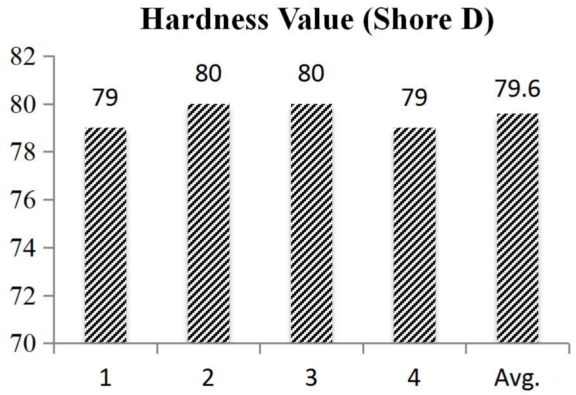

Figure 1. Hardness test results

The Izod impact test results are given in Table 4 below. When the average of the results is taken into consideration, a result of 9,27 kJ/m^2 has been reached. Buys *et al*.[12] In a study examining the mechanical properties of PLA / NBR composites, the results of the notched impact test of pure PLA were found to be 4,14 kJ/m^2. In another study, Oksman *et al*.[13] studied the PLA / linen composite and found that the non-indented Charpy impact test result was 14 kJ/m^2.

The tensile test results of 3 test samples are given in Table 5 and Figure 2. When we look at the average value of the tensile strength values of sample 3, it is seen to be 46.88 MPa. Oksman et al.[13] found that the tensile strength value of pure PLA was 50 MPa. Buys et al.[12], this value is 35 MPa and Reinhardt et al.[14] recorded a value of 59 MPa in the work they did. Likewise, when we examine the elastic modulus value in Table 5, the average value is 2.46 GPa. Oksman et al. the elastic modulus is a value of 3.4 GPa. When we look at the average% elongation value in Table 5, it is seen that there is a stretch of 2.57%. Reinhardt et al. found a% elongation value of 2.5% in his work. Oksman et al. found 2% of this value in their work. Buys et al. In the study, this value was 2.09%.

Test Piece	Fracture	E_s [J]	E_y [J]	E_g [J]	E_1 [J]	E_2 [J]	R_e [kJ/m^2]
1	N	0,0450	1,7381	1,6930	5,3562	3,6181	8,2408
2	N	0,0225	2,2345	2,2120	5,3451	3,1106	10,8008
3	N	0,0450	1,5671	1,5220	5,3451	3,7780	7,4293
4	N	0,0225	2,2711	2,2486	5,3451	3,0740	10,9113
5	N	0,0112	1,8347	1,8234	5,3451	3,5104	9,0160
Avg.		0,0292	1,9291	1,8998	5,3473	3,4182	9,2796

Eg: E-friction, E: E-load, Eg: E-real, E1: E in alpha, E2 in E: Beta, Re: Eg/Field.

Table 4. Impact test results

Test Piece	Tensile Strength (MPa)	Elastic Module (GPa)	Elongation %
1	48,317	2,560	2,634
2	44,387	2,406	2,395
3	47,956	2,423	2,690
Avg.	46,887	2,463	2,573

Table 5. Tensile test results

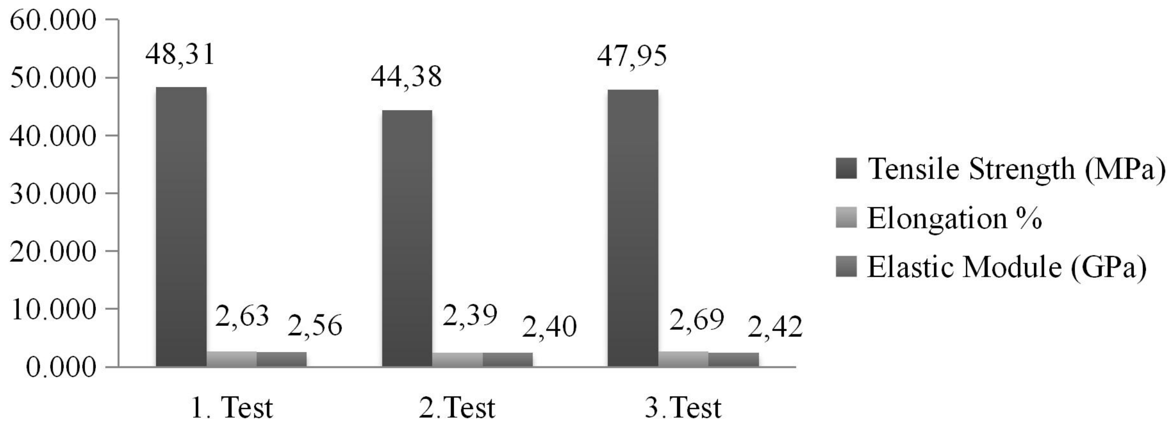

Figure 2. Tensile test results

Wear tests were carried out under sliding loads of 0.5, 1 and 1.5 m/s and loads of 2, 5 and 10N. The wear rates depending on the applied speed and load are shown in **Figure 3** and **Figure 4.** At about 0.5 m/s, the same wear rates were observed at 2 and 5N, but there was a high increase in wear at 10N. In the same way, at a speed of 1 m/s, the wear rates of 2 and 5N are close to each other, but an increase at 10N is observed. At a speed of 1.5 m/s, the wear rates at 2, 5 and 10N are quite high.

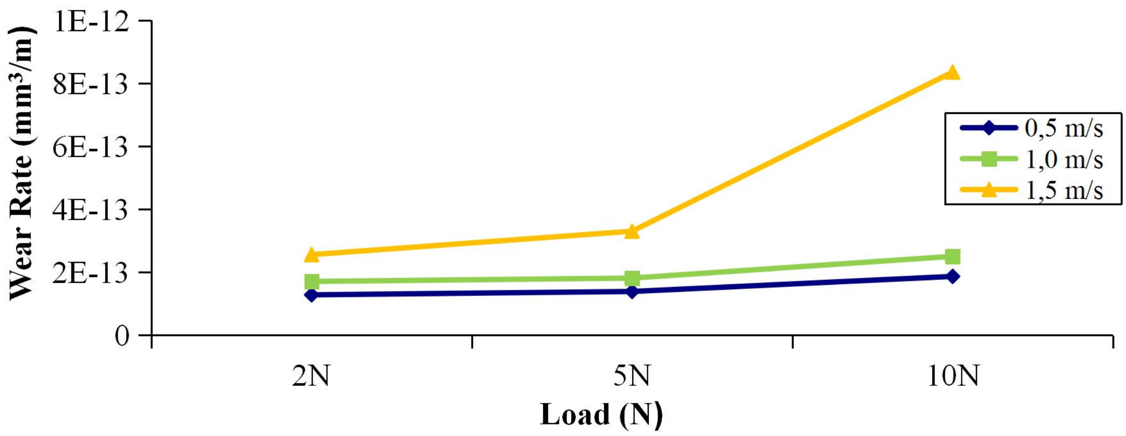

Figure 3. PLA wear rate-load

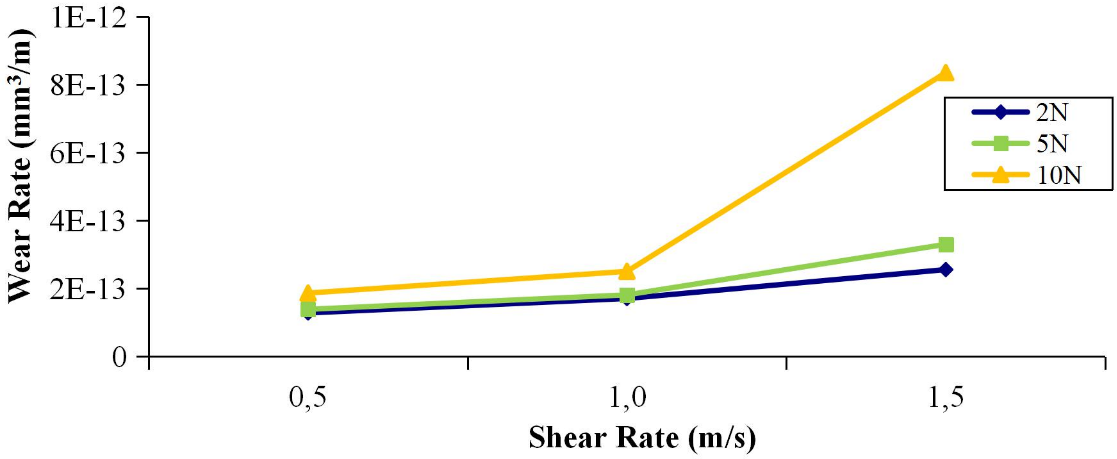

Figure 4. PLA wear rate-speed

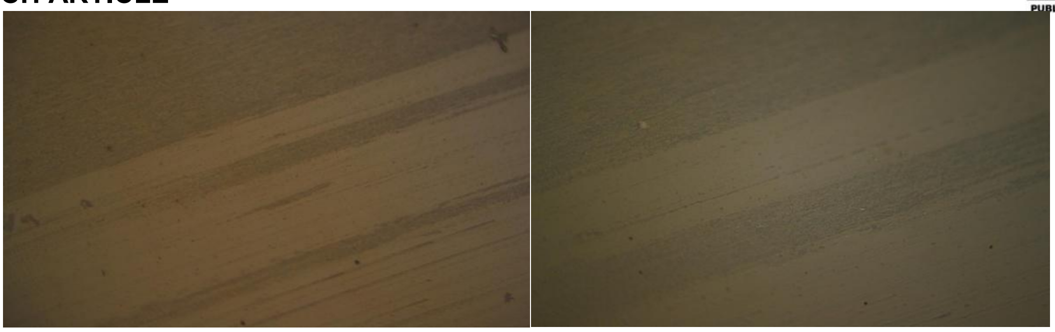

Figure 5. Optical microscope views of the worn surface

As seen in the graphs, the rate of wear increases with the increase in speed and load. Especially at 10N load and 1.5 m/s shear rate, the wear rate is increased about 3 times. This change in wear rate can be attributed to the increased load and the effect of the intermediate layer between the sample and the disc.

4. Conclusions

In this study, it is aimed to investigate the usability of PLA as a matrix by injection method. In addition to being able to be handled from renewable sources, mechanical testing results also show that PLA, a thermoplastic biopolymer, can replace most commonly used industrial polymers. It has been determined that PLA is fragile in the tensile test results, but it is possible to eliminate this disadvantage with some additives. For this reason, work should be continued for PLA / fiber reinforced composite materials which offer an alternative to composite materials used in many sectors. It is thinked that the pure PLA with a hardness value of 79.6 can be further enhanced by fiber reinforcements. It is also considered that the tensile strength of the PLA with the impact strength value of 9.27 kJ/m^2 can be increased by fiber reinforcements in the same way. Thus, it will be possible to reduce the dependence on the polymers obtained from petroleum-based sources and to avoid pollution and produce more superior materials.

Acknowledgement

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