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Original Research Paper-Engineering

Investigating the Mechanical Properties of Polypropylene in the Presence of Biodegradable Additive

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ABSTRACT:

Products made from polyolefins have developed significantly in recent decades thanks to their cost-effectiveness, suitable weight, and acceptable physical properties. These properties have made polyolefins a good choice for many applications, especially in the packaging industry. Hence, a crucial problem in this regard is burying these materials after consumption. Polyolefins are not easily degraded in nature. This issue makes the production of degradable polyolefins one of the most important research subjects. The present study aims to investigate the biodegradability of BOPP (Biaxially Oriented Polypropylene), which is a grade of polypropylene used extensively in the food packaging industry. This work is done using commercially available biodegradable additives. This study uses a suitable additive that accelerates the reaction of plastic with air oxygen and connects oxygen atoms to polyolefin chains. The use of P-life additive in polymer improved polymer biodegradation. This additive did not cause significant changes in the mechanical and rheological properties of the polymer. This is an advantage of using biodegradable additives mixed with polymers such as polypropylene, which do not inherently have biodegradable properties.

Keywords: Polyolefins, Biodegradability, Polypropylene, Additive

INTRODUCTION:

Plastic plays a vital role in our daily life. The demand for plastic, especially plastic packaging, plastic handbags, thin films, etc., is increasing rapidly worldwide, leading to a growing problem of plastic waste. Plastic is the fastest-growing component of the waste stream. Plastic wastes have become a permanent environmental problem since most plastics are not necessarily biodegradable [1]. Many activities have been performed over the last few years to modify existing polymers to produce new materials with desirable properties. The increasing use of plastics in various industries and the production of a high level of waste due to these different uses have made the industries seek to find a compound that is most compatible with nature and causes the lowest damage to the surrounding environment. They decompose under the effect of biological factors such as heat, humidity, and sunlight after being used and placed in nature, and the minimum amounts of them are left in the environment while having good properties and similar to the original polymer [2].

Oxo-degradable plastics: These materials that contain oxidizers (oxo-degradable) have been developed and introduced to the packaging industry over the last few years [3]. They are the same ordinary plastics such as polypropylene to which oxidizers were added to cause the degradation of their polymer chains. Their degradation is in the form of oxidation. They are degraded via microorganisms by breaking the chains and shortening them [3].

Degradation mechanism of oxo-degradable plastics: Oxidizers cause the oxidation of polyolefin chains and shorten and break the chains under sunlight, UV rays, and the presence of oxygen [8,4]. The degradation mechanism is first done by oxygen in the oxidation form. Finally, microorganisms also cause degradation and increase the rate of disintegration with the shortening of polymer chains. Oxo-degradable materials are 100% biodegradable and will return to the environmental cycle within a few years [4].

INTRODUCTION OF MATERIALS

In this study, PP (a product of Jam Petrochemical Company of Iran) with the commercial characteristic of HP 525J, melt flow index of 25 g/10 min, melting temperature of 170 °C, and density of 0.9 g/cm3, was used. It is a biodegrading additive of p-life [5].

Introducing equipment and devices:

Oven device: In this study, this device was used to dry, heat, and remove moisture from materials including polypropylene and mixed materials at any time during the work process.

Internal micro compounder-mixer device

Hot press: To press the samples, a Dr. Kolin device, made in Germany, was used with a temperature setting of 180 °Cand a pressure of 150 bar.

TEST METHODS:

As stated earlier, the use of biodegradable additives that have a metal and inorganic base in the polymer mixture can significantly improve the biodegradation performance of the polymer. Hence, additives such as P-life, which has a manganese base [6] are used in the field of PP. Thus, one of the primary goals of this study is to investigate the effect of the presence of the additive and its amount on the mechanical properties of the mixture.

SAMPLE PREPARATION:

The calculations were first done based on the capacity of the tank of the microcompounder and according to the density of PP and P-life, and the pure sample prepared from PP and different percentages of P-life/PP mixture, including 99.1, 98.2, and 97.3 %, were mixed by the melt mixing method in the microcompounder.

Mixture optimization:

We first test four different percentages of composition. The table below shows the composition of different percentages.

Table 1-Composition of P-life additive percentages

Temperature	**190**
Time	15
Cycle	80

Row	Sample code	PP(HP525J)	P-life
1	100.0	100	0
2	99.1	99	1
3	98.2	98	2
4	97.3	97	3

Mixture:

The goal of the mixing process is to create a uniform mixture of PP and additive, which has given a biodegradable property to this polymer. First, the PP granule was weighed and the additive was weighed based on the determined ratio. Then, the temperature, time, and speed of the screws were adjusted. Accordingly, PP was first introduced into the feeding hopper. Then, the additives were added in specified ratios.

Table 2- Cycle, time, and set temperature used in the test using micro compounder

6-RESULTS:

Mixture tensile test:

In this section, the tensile strength and modulus of all the samples are examined and analyzed. The figure below shows the stress graph in terms of strain for four samples with different ratios. Based on an accepted principle, the mechanical properties of polymers depend on their Tg.

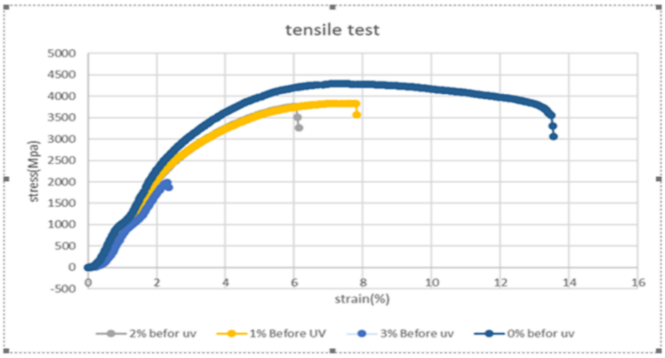

Figure 1 - Stress graph in terms of strain for four samples made of PP and PP containing 1, 2, and 3% of P-life biodegradable additive before exposure to the UV device

As seen in Figure 1, the addition of additive amounts to PP reduces mechanical properties. This reduction indicates the lowest value in 1% and the highest value in 3%. They create a weakness in the polymer structure. Its reason is the placement of additive particles among the polymer chains, which act like defects and create weak points in the polymer structure.

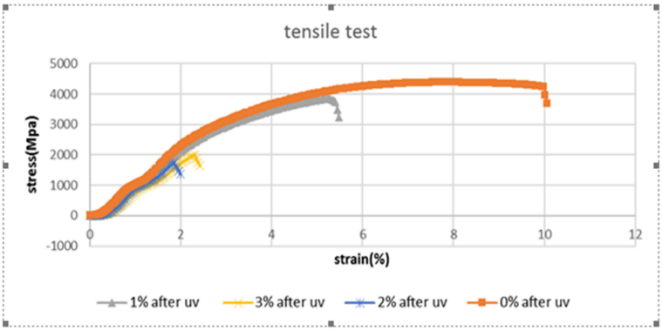

Figure 2 - Stress graph in terms of strain for four samples made of PP and PP containing 1, 2, and 3% of P-life biodegradable additive after one day of UV exposure

Dumbbells with a thickness of one millimeter were prepared based on the standard of sheets and films (ISO 527-33) and were exposed to QUV-B radiation for one day, with a relative humidity of 45%, and temperature of 50 to 60 degrees, and were subjected to a tensile test to determine the change in properties.

First, the sample prepared from pure polymer was compared before and after UV exposure (Figure 3).

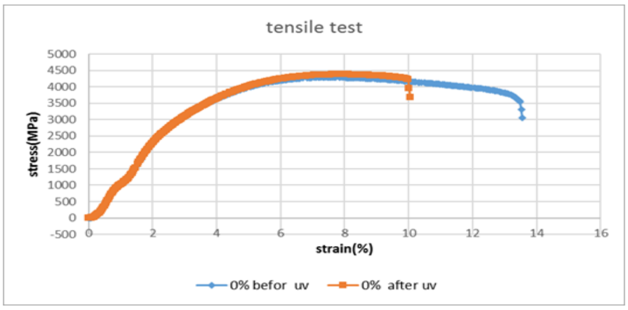

Figure 3 - Sample prepared from pure polymer, before, and after UV exposure

In the non-additive samples, Figure 3 shows a very small reduction in the properties, and after one day of UV exposure, the two graphs show a similar trend, and we see a good overlap in the initial parts.

Figure 4 compares the properties of the sample made of PP containing 1% additive, before, and after UV exposure

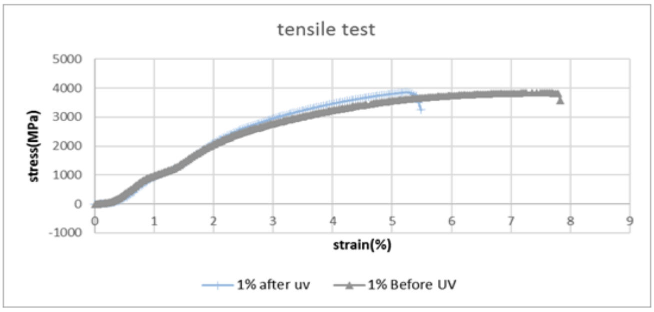

Figure 4- Sample made of PP containing 1% additive, before UV exposure and after UV exposure

In the 1% sample, the sample has become brittle after being exposed to UV, but it breaks later than other samples. In other words, the presence of the additive causes the polymer to degrade in the vicinity of UV, but compared to the samples containing 2% and 3%, they are more resistant to the non-UV state. Both of them are favorable results for us at the same time.

Figure 5 compares the properties of the sample made of PP containing a 2% additive, before and after UV exposure:

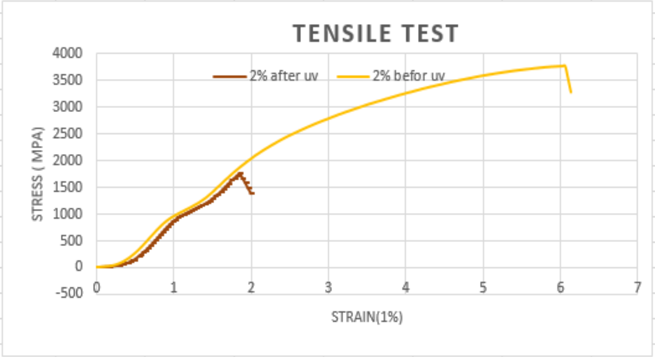

Figure 5- Sample made of PP containing 2% additive before and after UV exposure

In the samples containing 2% additives, the additive particles increased among the chains so much that they both accelerated the degradation of the polymer in the vicinity of UV and created defects between the chains. It caused the chains to break earlier and reduce the properties of the sample even in the non-UV state.

Figure 6 compares the properties of the sample made of PP containing 3% additive, before and after UV exposure:

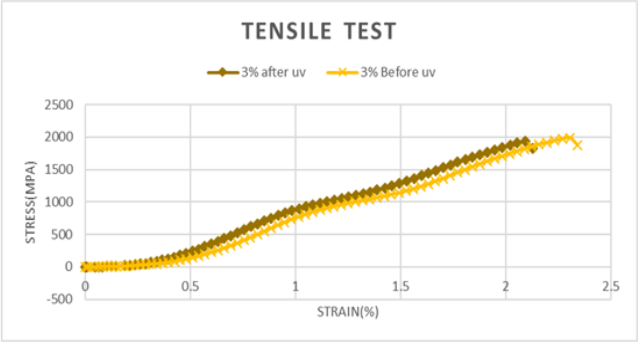

Figure 6 - Sample made of PP containing 3% additive before and after UV exposure

Increasing the presence of additive particles among the chains in both states (UV and non-UV exposure) significantly reduced the properties. Thus, this sample shows unfavorable results even in the non-exposure state. It is very weak and unusable in terms of properties.

Table 3- Values of elastic modulus, elongation at break, and strength of PP mixture and different amounts of P-life biodegradable additive

Sample	**Elastic Modulus (MPa)**	**Elongation at Break(%)**
PP-VIRGIN	542.385	13.559
PP1% additive	207.064	7.831
PP-2% additive	134.88	6.134
pp-3% additive	62.74	2.341

Table 4- Values of elastic modulus, elongation at break, and strength of PP mixture and different amounts of P-life biodegradable additive after one day of UV exposure

Sample	**Elastic Modulus (MPa)**	**Elongation at Break(%)**
PP-VIRGIN	279	10.057
PP1% additive	69.109	5.482
PP-2% additive	49.58	1.990
pp-3% additive	51	2.416

The samples were exposed to two different cycles of UV radiation and were evaluated at review times of 1 and 4 days [7]. All samples containing 1-3% biodegradable additive became brittle within 1 day of UV exposure. The following table presents the elastic modulus and strain at the breaking point for the samples after and before UV exposure.

The strain at break or the elongation percentage for PP containing P-life biodegradable additive decreased steadily from 1 to 3% additive. The effect of UV absorption is very effective and can immediately eliminate the properties of the polymer. This issue can be a reason for the brittleness of the polymer film after one day of UV exposure. Tensile properties and strain at break decreased to such an extent that the films became severely brittle after one day of UV exposure.

Tensile test of samples after 4 days of UV exposure

PP samples containing 1, 2, and 3% biodegradable additives were exposed to UV for 4 days. After 4 days, degradation rate of polymers increased significantly. Tensile test results for 4 days of UV exposure were also repeated and the results were compared with the samples before UV exposure.

For a better conclusion, we compare the sample prepared from pure polymer before UV exposure and 4 days after UV exposure (Figure 7):

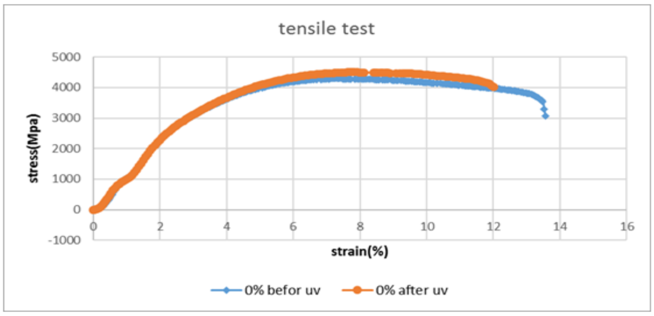

Figure 7- Comparison of the sample prepared from pure polymer before UV exposure and 4 days after UV exposure.

Figure 8 compares the sample prepared from the polymer containing 1% biodegradable additive before UV exposure and 4 days after UV exposure:

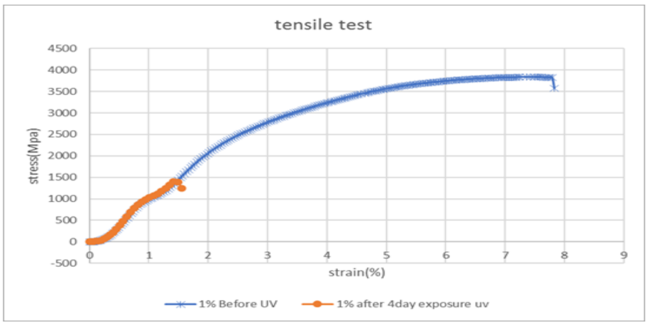

Figure 8: Sample prepared from polymer containing 1% biodegradable additive, before UV exposure, and 4 days after UV exposure

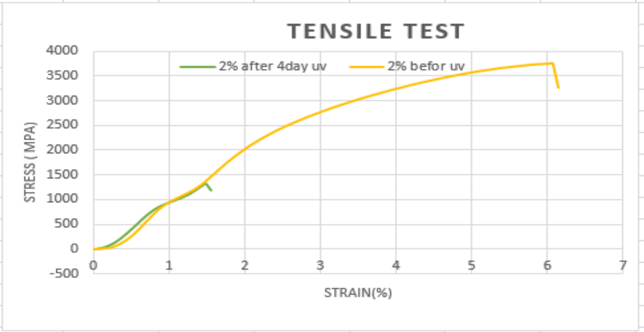

Figure 9: Sample prepared from polymer containing 2% biodegradable additive, before UV exposure, and 4 days after UV exposure.

Figure 10 compares the sample prepared from a polymer containing a 3% biodegradable additive, before UV exposure, and 4 days after UV exposure:

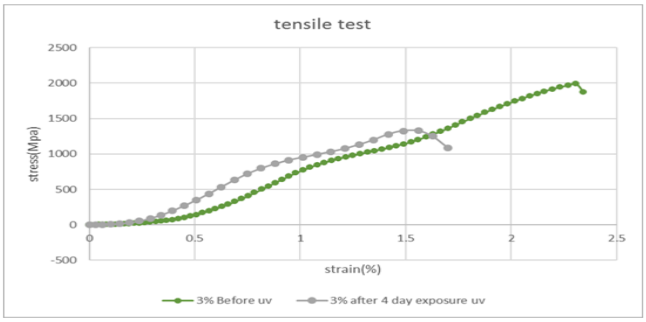

Figure 10: Sample prepared from a polymer containing 3% biodegradable additive, before UV exposure, and 4 days after UV exposure.

Table 5: values of elastic modulus, elongation at break, and strength of PP mixture and different amounts of P-life biodegradable additive after 4 days of UV exposure

Sample	Elastic Modulus (MPa)	Elongation at Break(%)
PP-VIRGIN	128.32	12.022
PP1% additive	47.026	1.559
PP-2% additive	40.97	1.515

The speed and severity of the degradation in the samples exposed to UV radiation for 4 days changed significantly in the repetition of the test.

CONCLUSION:

Hydroperoxide is the primary degradation product, which can do thermolysis or photolysis under the catalytic effect of a mineral, leading to chain scission and the production of oxidation products with low molecular mass, such as carboxylic acids, alcohols, ketones, and hydrocarbon waxes with low molecular weight. The present study investigated the effect of the presence of a type of biodegradable additive on the properties of plastic bags and packaging containers made of polypropylene. In this regard, sheets were prepared and experiments were done under different laboratory conditions, including heat, UV, and immersion in the soil. The results of the tensile test revealed that the addition of additives even in low percentages such as 0.5% to polypropylene reduced the modulus, and in combination with higher percentages, the observed reduction was greater (4). In the tensile test, the PP/P-life mixture decreased due to the decrease in Tg and the decrease in flexibility of the stress necessary for the creation and growth of cracks, resulting in a decrease in tensile strength. However, we observed that the elasticity increased by 1%.

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