# Degradative Analysis of Sodium Salt of Poly(Ethylene-Co-Methacrylic Acid) Compatibilized LDPE-Starch- Mixtures Containing Metal Stearates

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**Abstract.** Different weight percentages (0.5% and 1%) of ferric, manganese, cupric, magnesium, and zinc stearates were incorporated into low-density polyethylene-starch blends, compatibilized with 5% of sodium salt of poly(ethylene-co-methacrylic acid) ionomer. The role of trace amounts of metal stearates as pro-oxidants in these blends was evaluated through various methods, including mechanical properties, melt flow indices, biodegradability, photodegradability, photobiodegradability, water absorption, infrared spectroscopy, and scanning electron microscopy. The inclusion of metal stearates altered the mechanical characteristics of the mixtures. Several degradation experiments indicated that the addition of metal stearates enhanced the degradation potential of the blends. SEM micrographs confirm the biodegradation of pro-oxidant integrated mix samples.

***Keywords:*** metal stearates, biodegradability, photodegradability, photobiodegradability, pro-oxidant

## INTRODUCTION

Nowadays, there is a growing interest in the oxidative-biodegradation of polymers utilized in packaging applications. One common polyolefin polymer used in packaging is low density polyethylene which have long lifespan of hundreds of years because they do not tarnish when exposed to environmental microbes. But compared to other polyolefins, low density polythene is more susceptible to microbial outbreaks under specific circumstances (Ohtake et al., 1995). One workable option for accelerating the attack of microorganisms on LDPE is the buildup of natural polymers, such as starch, to assure at least partial biodegradation. Given that it is an inexpensive and easily accessible raw material, starch is a good choice (Inceoglu and Menceloglu 2013, Oner et al., 2019). The importance of starch-LDPE (low-density polyethylene) blends lies in their potential for biodegradable applications, particularly in the agriculture sector (Sabetzadeh et al., 2012). The resistance of LDPE to degradation poses environmental challenges, hence the integration of starch to create biodegradable polyethylene is significant for applications such as agricultural films and packaging, where the accumulation of plastic waste is a concern.

Interestingly, while the addition of starch to LDPE can improve biodegradability, it may also affect the mechanical properties of the blend. For instance, increasing the starch content in LDPE can lead to a reduction in Young's modulus and impact strength, which are critical for the durability of agricultural plastics (Hamza et al., 2009). However, the use of compatibilizers can enhance the interfacial properties between starch and LDPE (Leewajanakul et al., 2003), improving the tensile strength and elongation at break of the blends (Hamza & Kurian, 2021; Liu et al., 2003). This suggests that carefully formulated starch-LDPE blends can meet the mechanical requirements for agricultural use while offering improved environmental benefits.

The two main strategies that have been developed to overcome low density polyethylene's inherent resistance to biological attack are the insertion of functional groups into the polyethylene backbone and the blending of polyethylene with photo-initiating pro-oxidants capable of promoting the formation of free radical precursor moieties by photo-oxidation to induce cleavage of the macromolecular backbone (Sanniyasi, 2021; Ammala et al, 2011), which speeds up biodegradation and increases the low molecular weight fraction by chain scission (Ghatge et al, 2020; Jiang et al, 2020; Inceoglu and Menceloglu, 2013). It also increases the surface area due to embrittlement and the resulting track expansion (Ali et al, 2018). Furthermore, the formation of carbonyl groups on the surface of polyethylene increases its hydrophilicity. According to Roy et al. (2006), transition metals are effective photoinitiators for polyethylene. Most commercial photodegradable compositions contain transition metals, especially iron and manganese, because of their exceptional capacity to degrade the hydroperoxides produced during the oxidation process of polymers [Bardaji et al, 2020].

Starch-LDPE blends represent a promising approach to developing environmentally friendly materials for agriculture, addressing the need for biodegradable alternatives to conventional plastics. The role of these blends in agriculture is to provide a sustainable option that can reduce plastic waste without compromising the functional requirements of agricultural films and packaging. The successful application of these materials depends on achieving a balance between biodegradability and mechanical performance, which can be facilitated by the use of compatibilizers and optimized formulations (Liu et al., 2003; Sabetzadeh et al., 2012).

The present study examines the effect of metal stearates (ferric stearate, manganese stearate, cupric stearate, magnesium stearate and zinc stearate), to enhance the degradative properties of low density polyethylene-starch blends that are compatibilized with sodium salt of poly(ethylene-co-methacrylic Acid), EMA-Na. The sample designations and descriptions used in this work are displayed in Table 1. The films were characterized by mechanical properties, scanning electron microscopy, thermal properties, and infrared spectroscopy. We also examined the films' photodegradability, biodegradability, and photobiodegradability.

**Table 1. Description of sample designations**

| Sample designation | Description |
|---|---|
| LDS-Na | LDPE-20% starch-5% (EMA-Na) |
| LDS-Na-Fe | LDPE-20% starch-5% (EMA-Na)- ferric stearate |
| LDS-Na-Mn | LDPE-20% starch-5% (EMA-Na)- manganese stearate |
| LDS-Na-Cu | LDPE-20% starch-5% (EMA-Na)- cupric stearate |
| LDS-Na-Mg | LDPE-20% starch-5% (EMA-Na)- magnesium stearate |
| LDS-Na-Zn | LDPE-20% starch-5% (EMA-Na)- zinc stearate |

## MATERIALS AND METHODS

### Materials

### LDPE

Periyar Polyfilms, Edayar, Kerala, India, supplied the film grade low density polyethylene (LDPE 24FS040) from Reliance Industries Limited, Mumbai, India, with a melt flow index (190 °C/2.16 kg) of 4 g/10 min and a density (23 °C) of 0.922 g/cm3.

### Starch

Jemsons Starch & Derivatives, Aroor, Alappuzha, Kerala, provided the tapioca starch (100 and 300 mesh). Before mixing, these fillers were oven dried for one hour at 120 °C due to their hygroscopic nature.

### Ionomers

The poly (ethylene-co-methacrylic acid) sodium salt (HIMILAN 1702 EMAANa) with a melt flow index of 190 °C/2.16 kg and a retention time of 10 g/10 min was the ionomer employed in this investigation. The Japanese company Mitsubishi Plastics, Inc. provided these ionomers.

### Pro-oxidants

This study employed metal stearates, specifically ferric, manganese, cupric, magnesium, and zinc stearates, as pro-oxidants. China's Jingjiang Concord Plastics Technology Co. Ltd. provided the ferric, manganese, and copper stearate. The suppliers of magnesium and zinc stearate were Alfa Chemicals, located in Ernakulam, Kerala, India.

### Methods

### Preparation of blends

For melt mixing, a Thermo Haake Polylab system (Rheocord 600p) with roller-type rotors was utilized. 69 cm$^3$ is the volumetric capacity of the mixing chamber. For every compound, an 8-minute mixing period was specified at 150°C and 30 rpm of rotor speed. The LDPE and ionomer were melted together for two minutes before the filler was added. Six more minutes of mixing were spent.

### Preparation of test specimens

The compounds and neat LDPE were molded for five minutes at 150 °C and 20 MPa of pressure in an electrically heated hydraulic press to make the test specimens. Samples were molded and then cooled under pressure to room temperature.

### Characterization

### Mechanical properties

Using a Shimadzu Autograph AG-I series universal testing machine with a crosshead speed of 50 mm/min, the mechanical properties were assessed. As per ASTM D-882 (2002), measurements of tensile strength, elongation at break, and elastic modulus were made. For every data point, averages of a minimum of five sample measurements were obtained.

### Melt Flow Index (MFI)

Using a 2.16 kg load and a melt temperature of 190 °C, the melt flow index (MFI) of each blend of LDPE with filler was determined using a CEAST Modular Line Melt Flow Indexer in compliance with ASTM method D-1238.

### Biodegradation studies

In compliance with ASTM D-6691, the mixes' biodegradation investigations were conducted. The Department of Biotechnology, Microbial Genetic Lab, Cochin University of Science and Technology, provided the bacterial cultures. These cultures were isolated from sediment samples that were taken from various backwater areas in Cochin and the mangroves of Mangalavanam. Based on the physical and biochemical traits listed in Bergey's Manual of Systematic Bacteriology ((Rosa et al., 2009))., these cultures were originally classified as belonging to the genus Vibrionacea. Using the paraffin oil overlay process, they were preserved in glass 10 mL bottles.

The consortium's individual isolates were cultured in nutritional broth (Himedia, Mumbai) with a pH of 7.0 ± 0.3 and 1% NaCl for one night at 37 °C and 120 rpm on an Orbitek shaker (Scigenics Pvt. Ltd, Chennai, India) in order to prepare the inoculum. The cells were collected by centrifugation for 20 minutes at 5000 rpm (2292 g), followed by a physiological saline wash and pooling. 50 mL of the starch-free amylase minimum medium [16] was inoculated with 5 mL of this pooled culture (OD660 = 1). The only source of carbon in this medium was the samples made from the mixes that had previously been cleaned with 70% alcohol. For a duration of three months, incubation was place in the Orbitek environmental shaker at 37 °C and 120 rpm. The medium without the inoculum with corresponding starch-plastic blends and subjected to the same treatment as above were used as controls.

The soil burial test was also carried out to evaluate the biodegradability of the blends. Water absorption was measured using 3 x 1 inch film strips of <1mm thickness according to ASTM D-570-81 method.

### Photodegradation by UV rays

Plastic film samples used in this investigation were divided into 8 by 1 cm pieces and placed 30 cm away from a 30-watt shortwave UV light for a month. Next, tensile strength was measured with a universal testing apparatus. A Sartorius-0.1 mg electronic balance was used to determine the test specimens' average weight both before and after the degradation investigations.

### Fourier transform infrared spectroscopy (FTIR)

The FTIR spectra of the samples were recorded in the transmittance mode using a Thermo Nicolet, Avatar 370 FTIR spectrophotometer in the spectral range of 4000–400 cm$^{-1}$.

### Morphological studies

In the current study, the tensile fractured surfaces were placed upright on a metallic stub using conducting paint and silver tape. Within 24 hours of the fractures, the surfaces were sputter-coated with platinum in a JFC 1600 Autofine coater, and the results were viewed under a JEOL model JSM-6390LV scanning electron microscope (SEM).

## RESULTS AND DISCUSSION

### Mechanical properties

The tensile strength, elongation at break and elastic modulus of neat LDPE, LDPE-starch-(EMA-Na) blend and the blends containing the metal stearates as pro-oxidants are shown in Fig 1. In LDPE-starch-(EMA-Na) blends, the samples with ferric stearate and magnesium stearate show an improvement in tensile strength whereas the samples with other metal stearates show a reduction in the tensile strength. One of the key mechanical parameters assessed is the tensile strength of these materials, which denotes the maximum stress a material can withstand when subjected to pulling forces without fracturing. Notably, the figures reveal that the samples containing metal stearates exhibit tensile strength values within a comparable range to that of the pristine LDPE. The samples including ferric and magnesium stearates in the blends exhibit increased tensile strength, while the samples containing other metal stearates exhibit decreased tensile strength. This is significant because it indicates that the processing techniques and the presence of metal stearates have not induced premature degradation reactions within the materials (Pedroso & Rosa, 2005).

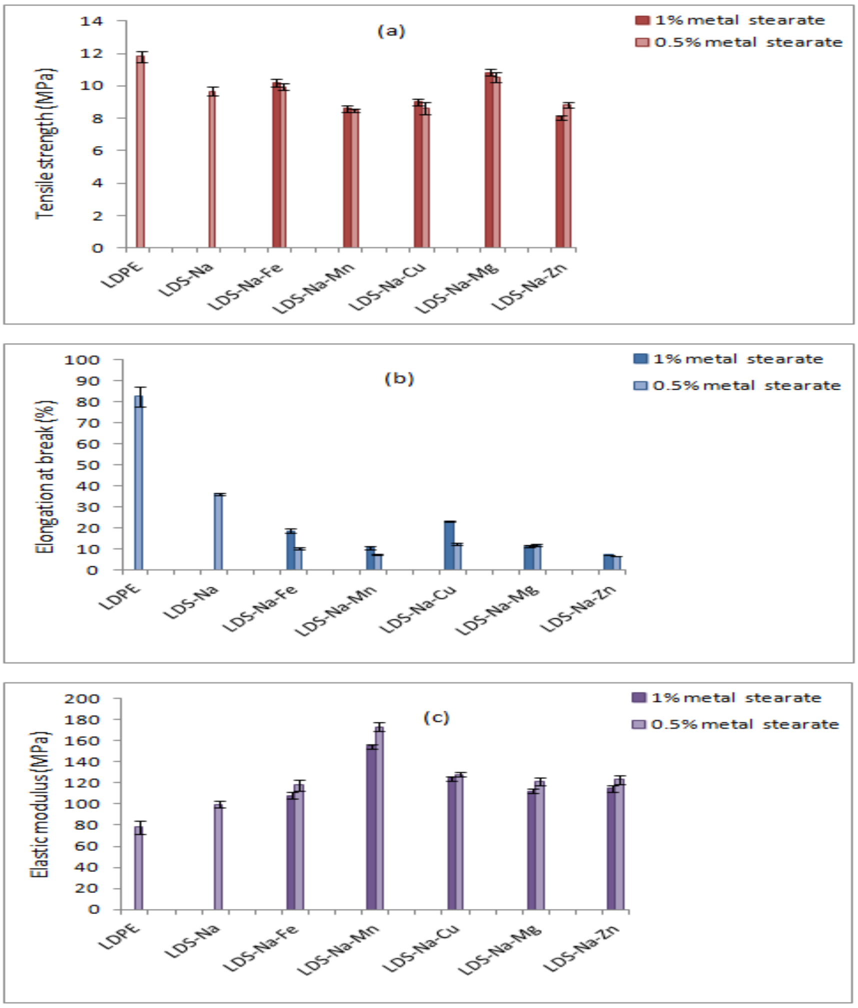


**Fig 1. Effect of metal stearates on the mechanical properties of LDPE-starch-(EMA-Na) blends**

When metal stearates were added, the elongation at break was less than when the basis material (LDPE-starch-ionomer blends) was used, as shown in Fig 1(b). The blends comprising metal stearates had an increase in elastic modulus, as shown in Fig 1(c). The values of all the blends were higher than the mix containing LDPE, starch, and ionomer. This indicates the existence of inflexible materials and the level of compatibility (Lucas et al., 2008).

### Melt flow measurements

A polymer's melt flow index (MFI), which is frequently used to assess processability, is correlated with its molecular weight distribution. The impact of metal stearates on LDPE-starch-(EMA-Na) blend melt flow indices is depicted in Fig 2. When compared to the LDPE-starch-(EMA-Na) mix, the MFI value of every sample increases. Magnesium, ferric, and zinc stearate samples showing a considerable improvement in MFI, a marker of large chain scission, are among the pro-oxidant-containing samples that were investigated.

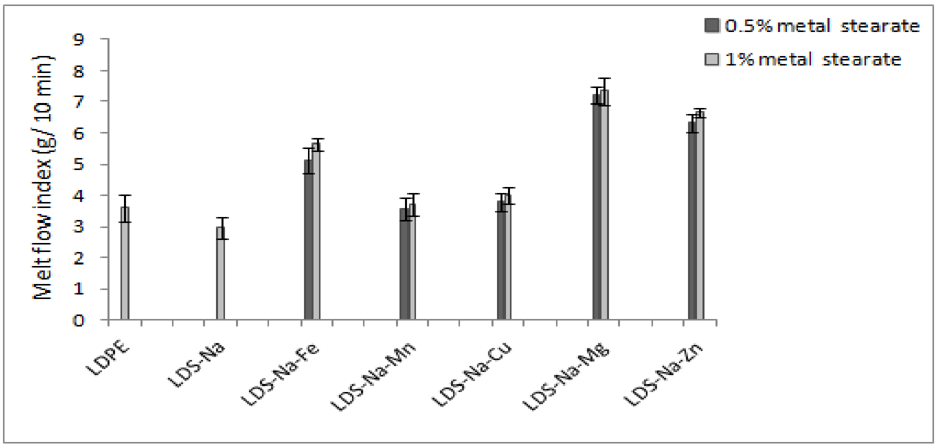


**Fig 2. Effect of metal stearates on the melt flow indices of LDPE-starch-(EMA-Na) blends**

### Biodegradation studies

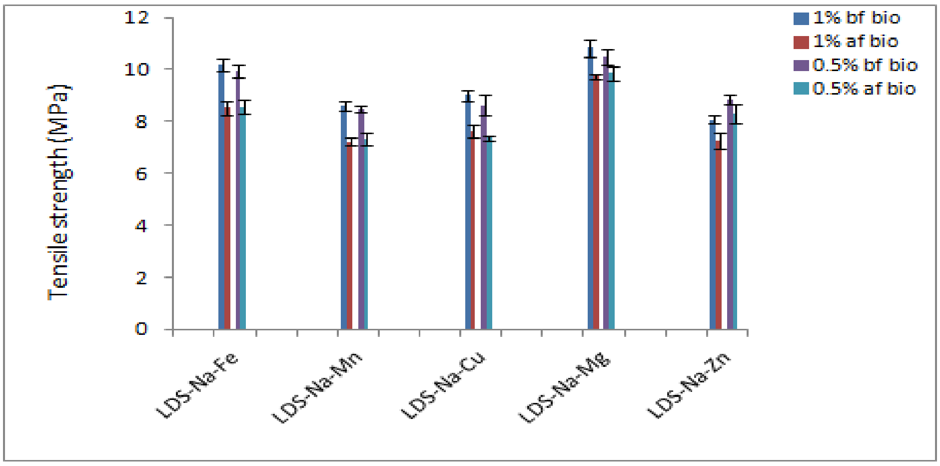


**Fig 3. Biodegradation of LDPE-starch-(EMA-Na)-metal stearate blends after biodegradation in culture medium for two months (Evident from tensile strength)**

Following two months of biodegradation in culture media, the tensile characteristics of LDPE-starch-(EMA-Na)-metal stearate blends are displayed in Fig 3. Table 2. provide the % decline in tensile strength for blends of LDPE-starch-(EMA-Na) metal stearate. For every mix, there is a notable decrease in tensile strength during biodegradation.

**Table 2.Percentage decrease in tensile strength of LDPE-starch-(EMA-Na)-metal stearate blends after biodegradation in culture medium for two months**

| Sample | Initial tensile strength (MPa) | Tensile strength after biodegradation for two months (MPa) | % decrease in tensile strength |
|---|---|---|---|
| LDS-Na(1)Fe | 10.2 + 0.24 | 8.53 + 0.27 | 16.19 |
| LDS-Na((0.5))Fe | 9.94 + 0.22 | 8.56 + 0.28 | 13.90 |
| LDS-Na(1)Mn | 8.60 + 0.20 | 7.21 + 0.15 | 16.10 |
| LDS-Na(0.5)Mn | 9.09 + 0.12 | 7.31 + 0.23 | 13.79 |
| LDS-Na(1)Cu | 9.00 + 0.21 | 7.64 + 0.26 | 15.16 |
| LDS-Na(0.5)Cu | 8.63 + 0.38 | 7.38 + 0.09 | 14.49 |
| LDS-Na(1)Mg | 10.8 + 0.35 | 9.73 + 0.10 | 10.18 |
| LDS-Na(0.5)Mg | 10.5 + 0.31 | 9.85 + 0.30 | 6.26 |
| LDS-Na(1)Zn | 8.06 + 0.15 | 7.25 + 0.32 | 10.09 |
| LDS-Na(0.5)Zn | 8.84 + 0.16 | 8.31 + 0.37 | 5.97 |

Microorganisms' consumption of starch is the cause of the decrease. The blends may be partially biodegradable based on these modifications, which are reflected in the mix films' tensile characteristics. Table 3. summaries the blends' % weight loss during biodegradation in culture media. After breaking down in culture media, all of the samples showed a notable weight loss, suggesting that the LDPE-starch-ionomer blends containing metal stearates are only partly biodegradable.

**Table 3. Percentage decrease in weight of LDPE-starch-(EMA-Na)-metal stearate blends after biodegradation in culture medium for two months**

| Sample | Initial weight (g) | Weight after two months (g) | % weight loss |
|---|---|---|---|
| LDS-Na(1)Fe | 0.4166 | 0.4039 | 3.05 |
| LDS-Na((0.5))Fe | 0.4808 | 0.4683 | 2.60 |
| LDS-Na(1)Mn | 0.6725 | 0.6497 | 3.39 |
| LDS-Na(0.5)Mn | 0.6265 | 0.5819 | 7.31 |
| LDS-Na(1)Cu | 0.5970 | 0.5820 | 2.51 |
| LDS-Na(0.5)Cu | 0.5360 | 0.5231 | 2.40 |
| LDS-Na(1)Mg | 0.6553 | 0.6359 | 2.98 |
| LDS-Na(0.5)Mg | 0.6931 | 0.6734 | 2.84 |
| LDS-Na(1)Zn | 0.4932 | 0.4799 | 2.70 |
| LDS-Na(0.5)Zn | 0.6545 | 0.6997 | 2.26 |

### Photodegradation studies

After a month of UV exposure, Fig 4. shows the tensile properties of blends of LDPE, starch, (EMA-Na), and metal stearate. Table 4 shows the percentage decrease in tensile strength for LDPE-starch-(EMA-Na)-metal stearate blends. After one month of exposure to UV radiation, there is a noticeable decrease in tensile strength. One of the possible causes of the decrease in tensile strength could be the formation of new groups in the polymer chain as a result of the blend's altered chemical structure following exposure to UV radiation, primarily in the amorphous region of the material (Bremner et al., 1990). Following a month of UV exposure, Tables 5. displays the percentage weight loss for blends of LDPE, starch, ionomer, and metal stearate. Following photodegradation, it was noted that every sample had a slight weight decrease.

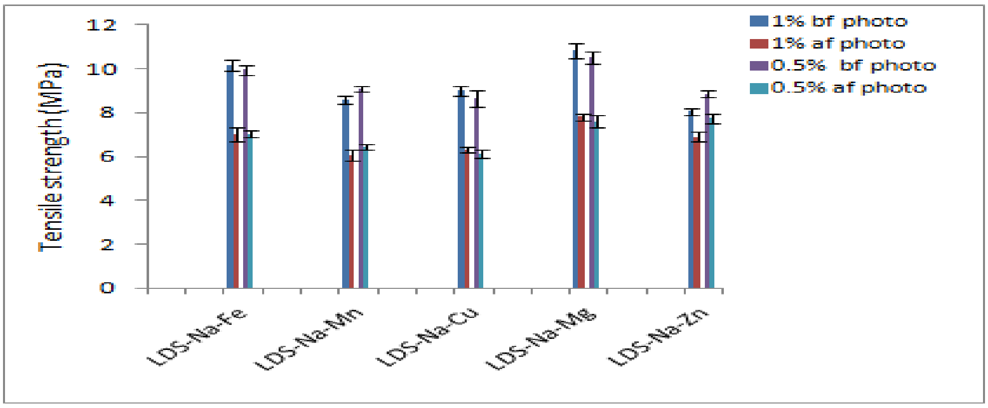


**Fig 4. Photodegradation of LDPE-starch-(EMA-Na)-metal stearate blends after UV exposure for one month (Evident from tensile strength)**

**Table 4. Percentage decrease in tensile strength of LDPE-starch-(EMA-Na)-metal stearate blends after UV exposure for one month**

| Sample | Initial tensile strength (MPa) | Tensile strength after UV exposure for one month (MPa) | % decrease in tensile strength |
|---|---|---|---|
| LDS-Na(1)Fe | 10.2 + 0.24 | 7.01 + 0.32 | 31.11 |
| LDS-Na((0.5))Fe | 9.94 + 0.22 | 7.02 + 0.15 | 29.38 |
| LDS-Na(1)Mn | 8.60 + 0.20 | 6.08 + 0.26 | 29.25 |
| LDS-Na(0.5)Mn | 9.09 + 0.12 | 6.45 + 0.11 | 29.05 |
| LDS-Na(1)Cu | 9.00 + 0.21 | 6.31 + 0.13 | 29.90 |
| LDS-Na(0.5)Cu | 8.63 + 0.38 | 6.12 + 0.17 | 29.04 |
| LDS-Na(1)Mg | 10.8 + 0.35 | 7.82 + 0.16 | 27.81 |
| LDS-Na(0.5)Mg | 10.5 + 0.31 | 7.59 + 0.28 | 27.77 |
| LDS-Na(1)Zn | 8.06 + 0.15 | 6.91 + 0.24 | 14.27 |
| LDS-Na(0.5)Zn | 8.84 + 0.16 | 7.75 + 0.23 | 12.34 |

**Table 5. Percentage decrease in weight of LDPE-starch-(EMA-Na)-metal stearate blends after UV exposure for one month**

| Sample | Initial weight (g) | Weight after one month (g) | % weight loss |
|---|---|---|---|
| LDS-Na(1)Fe | 0.5308 | 0.5302 | 0.113 |
| LDS-Na((0.5))Fe | 0.4437 | 0.4435 | 0.045 |
| LDS-Na(1)Mn | 0.4942 | 0.4934 | 0.162 |
| LDS-Na(0.5)Mn | 0.6044 | 0.6043 | 0.017 |
| LDS-Na(1)Cu | 0.4659 | 0.4640 | 0.408 |
| LDS-Na(0.5)Cu | 0.4955 | 0.4937 | 0.363 |
| LDS-Na(1)Mg | 0.6469 | 0.6466 | 0.046 |
| LDS-Na(0.5)Mg | 0.7792 | 0.7790 | 0.026 |
| LDS-Na(1)Zn | 0.5886 | 0.5877 | 0.153 |
| LDS-Na(0.5)Zn | 0.6660 | 0.6659 | 0.015 |

## Photobiodegradation studies

Tensile characteristics of LDPE-starch-(EMA-Na)-metal stearate composites during photobiodegradation experiments are displayed in Fig 5. In order to study photobiodegradation, the samples were first exposed to UV light for one month. After that, they were submerged for another month in a culture medium containing amylase-producing *Vibrios*, which were isolated from the marine benthic environment. Table 6. presents the % decline in tensile strength for blends of LDPE-starch-(EMA-Na) metal stearate. After two months of photobiodegradation, there is a noticeable decrease in tensile strength. This is due to the photo-oxidation of a polyethylene-starch blend that contains pro-oxidants, which causes chain scission to enhance the low molecular weight fraction and facilitate biodegradation (Ghatge et al, 2020).

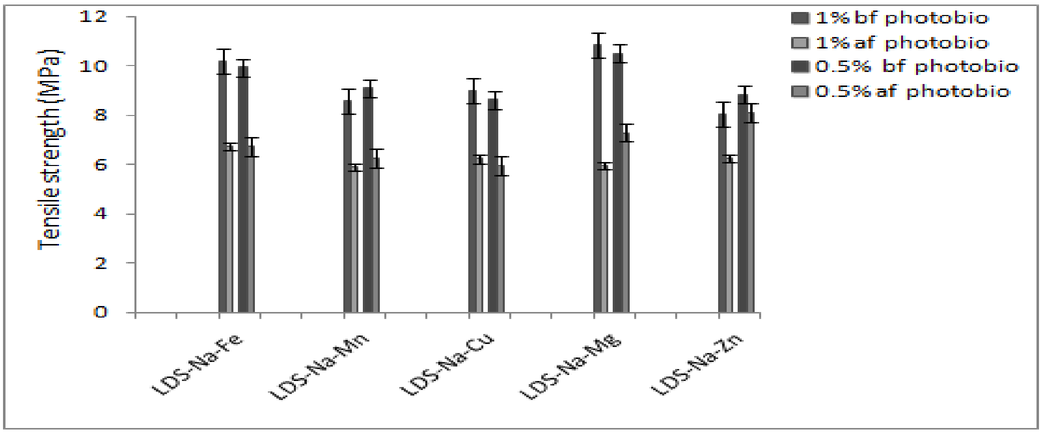


**Fig 5. Variation in tensile strength of LDPE-starch-(EMA-Na)-metal stearate blends after UV exposure for one month followed by biodegradation in culture medium for one month**

**Table 6. Percentage decrease in tensile strength of LDPE-starch-(EMA-Na)-metal stearate blends after UV exposure for one month followed by biodegradation in culture medium for one month**

| Sample | Initial tensile strength (MPa) | Tensile strength after photobiodegradation for two months (MPa) | % decrease in tensile strength |
|---|---|---|---|
| LDS-Na(1)Fe | 10.2 + 0.24 | 6.75 + 0.12 | 33.65 |
| LDS-Na((0.5))Fe | 9.94 + 0.22 | 6.75 + 0.23 | 32.09 |
| LDS-Na(1)Mn | 8.60 + 0.20 | 5.88 + 0.11 | 31.58 |
| LDS-Na(0.5)Mn | 9.09 + 0.12 | 6.25 + 0.20 | 31.25 |
| LDS-Na(1)Cu | 9.00 + 0.21 | 6.22 + 0.11 | 30.90 |
| LDS-Na(0.5)Cu | 8.63 + 0.38 | 5.94 + 0.22 | 31.13 |
| LDS-Na(1)Mg | 10.8 + 0.35 | 7.56 + 0.13 | 30.21 |
| LDS-Na(0.5)Mg | 10.5 + 0.31 | 7.29 + 0.25 | 30.62 |
| LDS-Na(1)Zn | 8.06 + 0.15 | 6.24 + 0.12 | 22.58 |
| LDS-Na(0.5)Zn | 8.84 + 0.16 | 8.09 + 0.21 | 8.49 |

Table 7. summarizes the blends' percentage weight loss following biodegradation in culture medium. Following photobiodegradation, a notable reduction in weight was seen in all of the samples. The oxidation products' microbial breakdown is the reason of this.

**Table 7. Percentage decrease in weight of LDPE-starch-(EMA-Na)-metal stearate blends after UV exposure for one month followed by biodegradation in culture medium for one month**

| Sample | Initial weight (g) | Weight after two months (g) | % weight loss |
|---|---|---|---|
| LDS-Na(1)Fe | 0.5308 | 0.5229 | 1.49 |
| LDS-Na((0.5))Fe | 0.4437 | 0.4380 | 1.29 |
| LDS-Na(1)Mn | 0.4942 | 0.4895 | 0.95 |
| LDS-Na(0.5)Mn | 0.6044 | 0.5990 | 0.89 |
| LDS-Na(1)Cu | 0.4659 | 0.4575 | 1.80 |
| LDS-Na(0.5)Cu | 0.4955 | 0.4901 | 1.09 |
| LDS-Na(1)Mg | 0.6469 | 0.6375 | 1.45 |
| LDS-Na(0.5)Mg | 0.7792 | 0.7685 | 1.37 |
| LDS-Na(1)Zn | 0.5886 | 0.5814 | 1.22 |
| LDS-Na(0.5)Zn | 0.6660 | 0.6589 | 1.07 |

## Water absorption studies

Table 8. displays the properties of LDPE-starch-ionomer-metal stearate blends' water absorption. As the concentration of metal stearate rises, the tendency to absorb water diminishes. This could be because the metal stearate particles are occupying the free volume in the polymer matrix, blocking the entry of water molecules.

**Table 8. Water absorption of LDPE-starch-(EMA-Na)-metal stearate blends**

| Sample | Initial weight (g) | Weight after 24 hours (g) | % water absorption |
|---|---|---|---|
| LDS-Na(1)Fe | 0.2868 | 0.2903 | 1.22 |
| LDS-Na((0.5))Fe | 0.3069 | 0.3107 | 1.24 |
| LDS-Na(1)Mn | 0.4183 | 0.4225 | 1.00 |
| LDS-Na(0.5)Mn | 0.3267 | 0.3304 | 1.13 |
| LDS-Na(1)Cu | 0.2937 | 0.2965 | 0.95 |
| LDS-Na(0.5)Cu | 0.3913 | 0.3953 | 1.02 |
| LDS-Na(1)Mg | 0.5254 | 0.5302 | 0.91 |
| LDS-Na(0.5)Mg | 0.3892 | 0.3929 | 0.95 |
| LDS-Na(1)Zn | 0.6878 | 0.6923 | 0.65 |
| LDS-Na(0.5)Zn | 0.4361 | 0.4397 | 0.83 |

**FTIR spectroscopy**

In Fig 6. the FTIR spectra of the blends of LDPE, starch, and EMA-Na, containing 1% ferric stearate, is displayed. Typical absorption peaks are visible in the spectra, and Table 9. reports them. We attribute the peaks in the 3700-3200 cm$^{-1}$ area to the O-H stretching vibrations of the water molecules. According to reference (Chaoui et al., 2020), C-H stretching is the cause of the doublet peaks seen in the 2965-2800 cm$^{-1}$ region. It is normal for stearates to have carboxylate asymmetric stretching vibration bands close to 1540 cm$^{-1}$. Peak intensities at 1473–1463, 1156–1028, 2921–2848, and 730–720 cm$^{-1}$ all showed some improvement after two months of biodegradation in culture medium. This improvement was likely brought about by the polyethylene chain breaking in degradable settings, which increased the number of terminal groups.

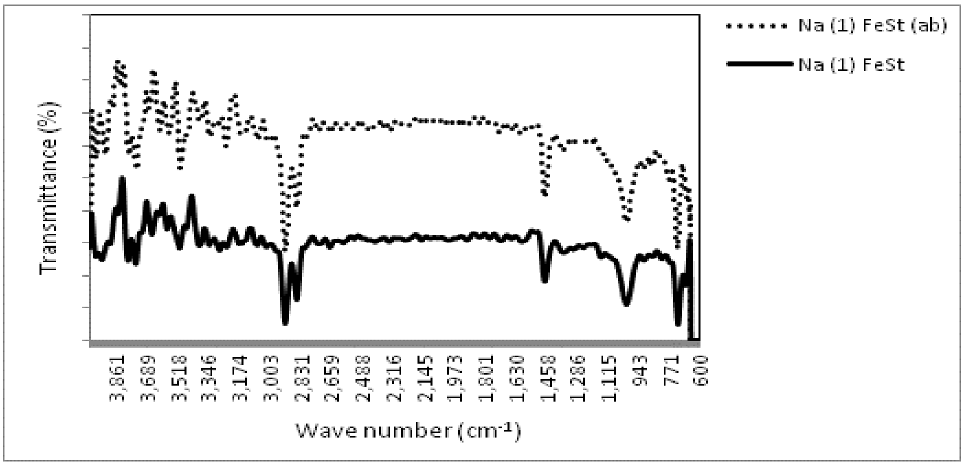


**Fig 6. FTIR spectra of LDPE-starch-(EMA-Na)-1% ferric stearate blend:**
(─ ) before biodegradation and (…) after biodegradation

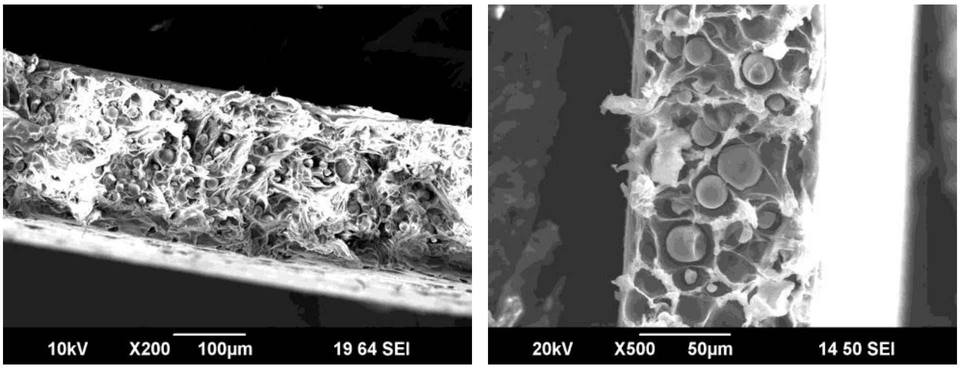
**Table 9. Characteristic FTIR spectral peaks**

| | Peak position (cm$^{-1}$) | Characteristic group |
|---|---|---|
| **LDPE-starch-(EMA-Na)-1% ferric stearate** | 2911, 2847 | C-H symmetric stretching |
| | 1590 | C=O stretching |
| | 1463 | $CH_2$ scissor and asymmetric bending |
| | 1357 | C-H bending |
| | 1008 | O-C stretching |
| | 916 | O-H deformation |
| | 721 | $CH_2$ rocking |

The middle-intensity C-H bond bending vibration, symmetrical stretching vibration of C-H bonds, and the distinctive absorption of the crystalline and amorphous bands are responsible for the peaks at 2921–2848 cm$^{-1}$, 1473–1463, and 730–720 cm$^{-1}$. The starch's C-O-C bond stretching is responsible for the peaks at 1028 and 1156 cm$^{-1}$, while the O-C stretch is characterized by the peak close to 1019 cm$^{-1}$. The presence of significant variations following biodegradation in these areas suggests that blends containing ferric stearate have biodegraded.

**Morphological studies**

Scanning electron micrographs of fractured surfaces of LDPE-starch-(EMA-Na)-1% ferric stearate (75/20/5) blends before and after they have been subjected to biodegradation in culture medium are presented in Fig 7. After two months of biodegradation a number of small cavities are visible in the film due to the removal of starch by microorganisms. But the number of cavities after biodegradation is less in ferric stearate incorporated blend as compared to the LDPE-starch blend. This fact indicates that the ferric stearate used as pro-oxidant adversely affect the biodegradation of LDPE.



(a) (b)

**Fig 7. Scanning electron micrographs of LDPE-starch-(EMA-Na) (75/20/5) blend containing 1% ferric stearate as prooxidant: a) before biodegradation and b) after biodegradation for two months**

## CONCLUSIONS

When metal stearates, such as ferric, manganese, cupric, magnesium, and zinc stearates, are added to EMA-Na-compatible LDPE-starch blends, the tensile strength and elastic modulus increase and the elongation at break decreases. Nevertheless, the melt flow index of LDPE increases when minute amounts of metal stearates are included. FTIR spectroscopy confirms the biodegradation of the blends by microorganisms, as evidenced by the considerable drop in tensile strength of the samples upon immersion in culture medium. The potential for water absorption diminishes as metal stearate concentration rises. When LDPE-starch-ionomer blends are exposed to UV light, the presence of trace amounts of metal stearates causes the blends to degrade. Following photobiodegradation, the tensile strength and weight of every sample showed a considerable decrease. The rate of degradation in the order FeS > MnS > CuS > MgS is accelerated by the addition of the metal stearates. The biodegradation of the pro-oxidant integrated mix samples is verified by SEM micrographs.

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