PROGRESS IN APPLIED SCIENCE AND TECHNOLOGY

Faculty of Science and Technology
Rajamangala University of Technology Thanyaburi

Research Article

Influence of Cross-linker on Mechanical, Thermal, and Biodegradation Properties of Rice Starch-Based Low-Density Polyethylene Composites

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Abstract

In this article, rice starch (RS) was practically mixed with low-density polyethylene (LDPE) through a melt mixing procedure to form LDPE/RS composites. For this study, LDPE was combined with 10%, 20%, 30%, and 40% RS. The inclusion of RS in the LDPE has decreased the melt flow index (MFI), and the elongation at break, whereas the tensile modulus has increased. Investigations were done into how chemical crosslinking affected the mechanical, thermal, and biodegradation characteristics of RS-based composites as well as melt flow behavior. As a cross-linking agent, sodium trimetaphosphate (STP) was employed. The findings demonstrate that as RS content was increased, the MFI of LDPE/RS composites dropped. Crosslinked RS in LDPE/RS composites has been found to have a higher MFI than non-crosslinked RS composites. In contrast to other composites that show homogeneity, LDPE/RS composites have improved characteristics due to the cross-linked RS, which also leads to excellent RS dispersion. In comparison to non-cross-linked RS/LDPE composites, cross-linked RS/LDPE composites showed improved elongation at break and tensile modulus. The crystallization temperatures of LDPE/RS/STP mixtures were higher than those of LDPE/RS blends but comparable to those of virgin LDPE. Also, biodegradability tests were performed for various LDPE/RS composites. Besides, water absorption of cross-linked LDPE-RS composites was reduced. In conclusion, the mechanical, thermal, and degrading properties of the RS-mixed LDPE synthetic polymer are significantly controlled by RS content and modification procedures, opening up the possibility to regulate the polymer's properties for food packaging applications.

Keywords: Rice Starch, LDPE, Crosslinking Agent, Mechanical Properties, Thermal Properties

1. Introduction

The production and use of plastics worldwide have increased dramatically in the last two decades, exacerbating the problem of waste disposal. Synthetic polymers (such as polyethylene) are widely used in packaging industries, the production of bags, biomedical fields, composites, and agricultural mulches (1). Most of these polymers are single-use and must be discarded, which leads to the serious environmental impact of plastics accumulating due to their non-organic corrosion. The main obstacles to the biodegradation process are the hydrophobicity of LDPE, high molecular weight, and resistance to microbial invasion due to the lack of functional groups sensitive to bacterial invasion (2, 3). Many authors have developed solutions to the disposal problems of LDPE and many other non-biodegradable polymers used in the packaging industry. Some

of the methods mentioned for disposal include recyclables (4), chemical recovery (5), burning (6), etc. However, high costs and air pollution have become major barriers to most of these methods. The most ecologically friendly is the making of ecological polymers (7, 8).

Decomposable plastics are plastics that can be eroded by microorganisms like bacteria, algae, fungi, and others (9, 10), so their use does not impact the atmosphere. Decomposable plastics are produced from renewable ingredients or a mixture of synthetic (non-renewable) and natural (renewable) ingredients. The benefits of using natural ingredients as decomposable plastic ingredients are numerous, relatively cheap, readily available, and can be ruined by the atmosphere (11). Bangladesh is a tropical country and has abundant natural assets that can be used as raw ingredients for the production of decomposable plastics. One of the ingredients used in the production of decomposable plastics is biomass like potato starch, cassava starch, corn starch, sago starch, rice starch, lignin, and others. Starch is composed of branched and linear polymers and is frequently found in granule form. Rice starch can be used to make biodegradable plastics. Rice is the seed of a monoecious plant and its family name is Oryza sativa or Oryza glaberrima. It has several significant roles in Bangladesh, from food to work. More than half of Bangladesh's arable land and labor force use paddy. In contrast, rice starch comprises a high amount of amylose, which is a striking raw ingredient for use as an obstacle in packaging ingredients. Rice starch has been used to produce decomposable films to partly or fully substitute plastic polymers due to their low cost and renewable nature.

The mixing of starch with synthetic polymers has therefore become a multifaceted way of biodegrading polymers. The reason behind the mixture of starch with LDPE is that it is believed that if the biodegradable material (such as starch) is present in sufficient quantity in the polymer, it can be swallowed or attacked by microorganisms like soil bacteria and fungi. In waste disposal environments, the polymer matrix will lead to an increase in porosity, degradation, and loss of integrity. The plastic containing the remaining inert material will break down, divide into smaller molecules, and decompose (12). Previous studies have shown that adding starch to LDPE severely weakens the mechanical strength of the film and causes dimensional instability (13, 14). Starch and

polyethylene are other major barriers to mixing due to their polarity differences (2, 3). Another major disadvantage of starch as a biopolymer is its dominant hydrophilic character, rapid degradation rate, and poor mechanical properties. Starch modifications (physical, chemical, and enzymatic) have been reported for various properties, replacing some hydroxyl groups to improve the hydrophobicity of starch so that it blends with synthetically obtained organic polymers (15). Chemical treatments like grafting or crosslinking are capable of limiting unnecessary water swelling and macromolecular motion. We call cross-linking the joining of polymer molecules through a bond. The bond may be covalent, ionic, or the result of intermolecular forces, such as a hydrogen bond. Material crosslink density is required to evaluate the quality of cross-linked polymers. Furthermore, the optimization of curing environments and the adaptive scheme of inventive goods with enhanced mechanical and aging features are important. Classical crosslinking leads to modified starch used in food or paper additive applications where crosslinking happens in different media using a dry or semi-dry mixing procedure. For instance, starch linkages are typically obtained by modifying granular starch with the resulting crosslinking agents in various media: sodium trimetaphosphate (STP) (16), epiclorohydrin (EPI) (17), and sodium tripolyphosphate. In this study, the features of rice starch films were enhanced by chemical treatment, using a crosslinking agent like STP. In this article, the influences of cross-linking agents with STP on the mechanical and thermal features of the LDPE matrix were examined. In addition to the influence of RS concentration on the mechanical and degradation features of the RS-included LDPE matrix.

2. Experiment
2.1 Materials

Low-density polyethylene (LDPE) with a density of 0.919 g/cm^3 and a melt flow index of 2.0 g/10 min is used as the matrix material and obtained from Cementhai Co., Ltd. (Thailand). Aush paddy grains are used to produce rice, which is then converted into rice starch using an alkaline process. Local grocers provide rice, which contains 17% amylose and 83% amylopectin. Vidyasom Co., Ltd. (Thailand) provided the commercial-grade sorbitol that was purchased for use as a plasticizer. Sodium

trimetaphosphate (STP), a crosslinking agent, was purchased from Sigma-Aldrich Co. (St. Louis, MO, USA).

2.2. Methods
2.2.1 Preparing cross-linked rice starch
The Woo and Seib methodology was used to prepare crosslinked RS using STP (16). 100 g of virgin RS granules were combined with 250 ml of distilled water. STP (5 wt%), a cross-linking agent, was then added to the mixture and stirred while it was at room temperature. In order to prevent starch gelatinization, the pH of the slurry was subsequently brought down to 10.5, which was achieved by vigorously stirring in a 5% sodium hydroxide solution. The mixtures were heated to 50°C for one hour while being constantly stirred. In order to stop the process, the slurry was then adjusted to pH 5.5 by adding 1 g/1000 ml of HCl solution. Water was used to wash the starch slurry, and a 5% NaOH solution was used to neutralize it. The resulting slurry was centrifuged at 7000 rpm for 15 min, and the starch was then dehydrated at 50°C for 24 h.

2.2.2 LDPE/RS composites fabrication
Four distinct types of composites were created in the first step of the test using various RS percentages. As shown in Table 1, varying percentages of LDPE and RS were used to weigh LDPE and RS. Weighed LDPE and RS were premixed and blended for 5 minutes at 135°C in a Brabender mixer. The mixes that the Brabender created were then transported to a hydraulic device for compression. There are four steps in the compression process: heating, carrying, pressing, and cooling. The hot press was used in the first three phases, and the cold press in the final stage. A square steel frame with two additional steel plates on either side held the specimens in its middle. Two thin, smooth steel plates were sandwiched between these three layers of the thick plate. To prevent the polymer specimens from adhering to the steel plate, PET sheets were placed between the polymer surface and the plate. 160°C and 8 MPa were the molding temperature and pressure, respectively. The same equipment was used for both hot press and cold press operations, but different molds were used for each. The specimens are moved to the lower half of the machine for cold pressing after hot pressing in the upper part. On these first-stage specimens, mechanical and degradation investigations were carried out. The effects of crosslinking with STP on the mechanical and thermal characteristics of the composite specimens were investigated in the second stage of the experiment. During the mixing process, 5 wt% of STP and sorbitol (the plasticizer, 50 g/100 g of starch) were added to the LDPE-RS combination. The composite specimens were pressed beneath the hydraulic press after cross-linking.

Table 1 Several percentages of LDPE and rice starch in polymer composites.

Sample	LDPE (wt%)	Rice starch (wt%)	STP (wt%)
LDPE	100	0	-
A10	90	10	-
A20	80	20	-
A30	70	30	-
A40	60	40	-
B10	85	10	5
B20	75	20	5
B30	65	30	5
B40	55	40	5

A10: LDPE90/RS10; A20: LDPE80/RS20; A30: LDPE70/RS30; A40: LDPE60/RS40; B10: LDPE85/RS10/STP5; B20: LDPE75/RS20/STP5; B30: LDPE65/RS30/STP5; B40: LDPE55/RS40/STP5

2.2.3 MFI measurement
The melt flow index (MFI) of several samples was measured using an extrusion plastometer by ASTM D1238-01. The measurements used a load of 2.16 kg and a temperature of 180°C.

2.2.4 Mechanical characteristics determination
Tensile tests were performed to assess the impact of RS concentration and to more fully explore the impact of treatment techniques, such as crosslinking with STP, on the mechanical properties of the polymer. The Tinius Olsen H10KL (Column Digital Universal Testing Machine), which is equipped with 5 KN load cells, was used to evaluate the tensile characteristics elongation at break and tensile modulus in accordance with ASTM-D 638-03 standards (18). Each test consisted of four samples with a combined dimension of $165 \times 13 \times 3$ mm3, and the cross-head speed was set at 10 mm/min. The relative humidity was recorded at $60 \pm 5\%$ for all experiments, which were conducted at room temperature ($25 \pm 2°C$). Each arrangement's attributes were examined independently in five duplicate samples.

2.2.5 Morphological analysis

The failure modes and surface morphological variations of LDPE/RS blends were investigated using SEM. To avoid electrostatic charge while being tested, the specimens had a small film of carbon sputter-coated on them. For breakdown and testing beneath the cracked surface, the LDPE/RS combinations were submerged in liquid nitrogen.

2.2.6 Thermal properties

The thermal properties of the blends were determined by using a differential scanning calorimeter (Perkin Elmer DSC7). A standard made of indium was used to calibrate the equipment. A sample weighing 5 mg was used for the scanning process. All samples were stored in aluminum pans and subjected to 10°C/min temperature scans from 30 to 170°C while being purge-gased with argon. The maximum temperature on the first cooling curve was known as the crystallization temperature (T_c), and the maximum temperature on the second heating curve was known as the melting temperature (T_m).

2.2.7 Biodegradability test

For the purpose of conducting degradation studies, LDPE polymer samples having different concentrations of non-crosslinked and cross-linked RS (10%, 20%, 30%, and 40%) were buried for six months at a depth of 5 cm. Each type of composite was tested on four different specimens. The purpose of this study is to compare the variations in ruin kinetics caused by changes in RS content. The rate of degradation was calculated based on weight loss. Prior to burial, the composite samples were weighed and quantified using an electric equilibrium with a 0.1 mg resolution. Samples were unearthed and cleaned a month following burial to confirm complete removal of soil/mud. The samples were stored in a space that had enough fresh air for routine dehydration. The same electric equilibrium that was used to weigh the dry eroded specimens before the ruin began. As a result, it was established that the following specimens had lost a certain proportion of weight:

$$\text{Weight loss (\%)} = \frac{W_2 - W_3}{W_2} \times 100 \qquad (2.1)$$

where W_2 is the primary weight (i.e., weight before ruin) and W_3 is the final weight (i.e., weight after ruin).

2.2.8 Water absorption test

Prior to testing, virgin LDPE and composite samples ($7 \times 2\,\text{cm}^2$) were cut, dehydrated for five hours at 80°C in a vacuum oven, cooled in desiccators, and then weighed (W_1). After that, the samples were submerged entirely in distilled water for a period of thirty days. Following a predetermined amount of time in the water, the samples were removed, quietly dehydrated by sponging with a clean cloth, and then immediately weighed (W_2) to the nearest 0.001 g. Each sample's results are an average of five different tests. The water absorption capacity was determined as follows:

$$\text{Water absorption capacity (\%)} = \frac{W_2 - W_1}{W_1} \times 100$$
$$(2.2)$$

3. Results and Discussion
3.1 Melt flow index measurement

Table 2 provides MFI values for virgin LDPE, noncross-linked (LDPE/RS), and cross-linked (LDPE/RS/STP) composite samples. It can be seen that the MFI of virgin LDPE was greater than that of the LDPE/RS composite. It was found that the MFI of the LDPE/RS composite has decreased as the amount of RS has increased. The value of MFI decreases as the adhesiveness of the composite increases. MFI decreased due to RS particles being more viscous than LDPE. Nevertheless, the decrease in MFI becomes more stable with the incorporation of STP by decreasing the intermolecular forces within the polymer coil and increasing the molecular space (19), and increasing the MFI as an outcome of polymer mobility. At higher filler content, the composite melt flow is disrupted and the composite flow resistance increases further, which contributes to the smaller MFI of the composite. It was found that composites made of LDPE, RS, and STP have higher MFI than composites without STP. STP inclusion enhances the fluidity and lowers the viscosity of composites in LDPE/RS. The interface bond between the matrix and the filler has been strengthened by STP, resulting in enhanced flow characteristics for composite melting. Lower viscosity was observed in LDPE/RS/STP composites, which could indicate processing steps.

Table 2. Compositions and MFI of LDPE/RS composites without and with cross-linker.

Samples	LDPE (wt.%)	Starch (wt.%)	STP (wt%)	MFI (g/10 min)
LDPE	100	0	0	2.75±0.28
LDPE/RS composites				
A10	90	10	0	2.31 ± 0.25
A20	80	20	0	2.22 ± 0.19
A30	70	30	0	2.15 ± 0.21
A40	60	40	0	1.98 ± 0.15
LDPE/RS/STP composites				
B10	85	10	5	2.73 ± 0.18
B20	75	20	5	2.65 ± 0.22
B30	65	30	5	2.53 ± 0.19
B40	55	40	5	2.39 ± 0.14

A10: LDPE90/RS10; A20: LDPE80/RS20; A30: LDPE70/RS30; A40: LDPE60/RS40; B10: LDPE85/RS10/STP; B20: LDPE75/RS20/STP; B30: LDPE65/RS30/STP; B40: LDPE55/RS40/STP

3.2 Assessment of mechanical properties
3.2.1 Tensile features

The main objective of the tensile test is to determine how the composite's tensile characteristics are impacted by the RS content and cross-linking with STP. The tensile characteristics of the RS-incorporated LPDE matrix were directly impacted by the RS content and conversion procedure (crosslinking). The elongation at break decreased as the RS content increased in the composite sample, while the tensile modulus improved with the RS concentration increased as shown in Figures 1 and 2, respectively. The findings concur with those of other studies (20, 22). Given that LDPE is nonpolar and starch granules have -OH groups on their surface, the decrease in elongation at break with RS content can be explained by the fact that starch granules are significantly more hydrophilic than LDPE. Strong interfacial interactions, such as hydrogen bonds, do not form between LDPE and RS in this kind of system. Additionally, the interfacial bond is weakened by the presence of moisture by RS at the LDPE-RS interface. As a result, RS granules easily shatter as a result of LDPE's lack of elongation, which leads to the fracture of the composite sample at low levels of elongation. The reduction in elongation at break of the composites becomes more prominent as the starch content increases to higher percentages as shown in Figure 1. This might be owing to the fact that at larger RS contents, the RS-RS contact is more pronounced than the RS-LDPE interaction, which in turn reduces the composite sample's effective cross-sectional area due to the presence of RS particles. The operative stress experienced by the matrix is substantially higher because the driven stress is not transferred from the LDPE matrix to the stiff RS particles (23). Unlike elongation, the produced polymer's tensile modulus increased with increasing RS concentration (Figure 2). As previously indicated, as the RS content increases, the RS-RS interface becomes more noticeable than the RS-LDPE interface, leading to the aggregation of RS particles that are naturally harder or harder than the LDPE matrix (24). Even in cases where there isn't actual reinforcement, rigid fillers are typically known to increase a mixture's modulus (25). As a result, it is thought that the increased stiffness of RS particles is what causes the increase in the modulus of polymer mixtures with increasing RS content. The elongation at break of the resultant blends, especially at low RS contents, was improved when STP was added to LDPE/RS blends. When RS content was 30% or more, there was no difference between the various blends, indicating that the primary element affecting the property of elongation at break was the distance between the RS particles. When RS content was equal to or more than 30% in this case, the cross-linker had little to no impact on this attribute. By settling in between them and interacting with them, STP is thought to have improved the interfacial adhesion between the RS filler and the LDPE matrix. The process of stress transfer was significantly aided by the enhanced interfacial adhesion, which decreased the likelihood of interfacial debonding and improved elongation at break. In turn, this had an impact on the polymer's tensile properties. For instance, elongation toughens and increases tensile modulus. However, a thorough explanation of this phenomenon can be developed by research into acute bond strength, which is outside the purview of this initial study.
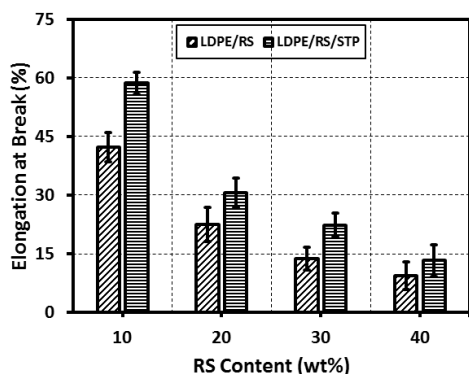
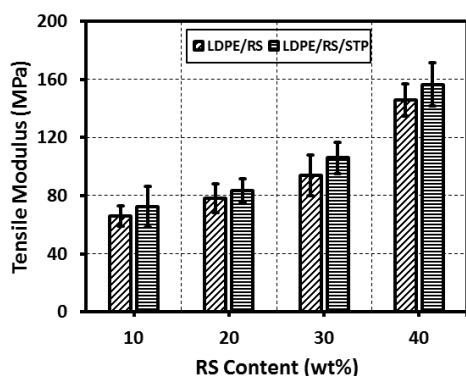**Figure 1** Effect of RS content on elongation at break (%) of LDPE/RS and LDPE/RS/STP composites.

Figure 2 Effect of RS content on tensile modulus of LDPE/RS and LDPE/RS/STP composites.

3.2.2 Morphological observation

Because it eventually impacts many features of the polymer blends, such as viscoelastic capabilities and solid mechanical and adhesive properties, the morphological structure of polymer blends is crucial (26). The SEM micrographs of LDPE/RS blends with various RS contents are shown in Figure 3. Even at low RS levels, the RS retained a granular at low RS levels, the RS retained a granular form, and agglomerates were seen, indicating a heterogeneous dispersion of RS in LDPE. The lack of contact but significant interfacial tension between RS and LDPE was inferred from the smooth surface of RS and the distinct interfacial appearance between RS and LDPE. Pushpadass (27) also believed that LDPE's non-uniform distribution in the starch linkage was caused by

the mixing of LDPE and corn starch. Starch is poorly distributed in LDPE because of the vast differences in their physical properties.

Figure 4 displays the LDPE/RS/STP blends' SEM micrographs. According to our preliminary findings, the STP addition was 5% of the RS weight. After the addition of STP, the dispersion of RS in the LDPE significantly improved in contrast to Figure 3 and there were fewer RS agglomerates visible, proving that STP was an effective cross-linking agent for RS in the LDPE. The reduced RS agglomeration was due to a higher interaction between RS and STP than between RS granules under the processing conditions, which also contributed to the enhanced dispersion. Although STP increased the dispersion of RS in the LDPE matrix, the interface between RS and LDPE was still distinct, resulting in poor interfacial adhesion between RS and LDPE. When STP was added, the line separating RS and LDPE became less visible in comparison to the blends without it (Figure 3), and the surface of RS became coarse, which is a common feature of STP blends. Although not completely smooth, the RS surface was covered in materials that stuck to the LDPE matrix. The materials on the RS surface were considered to be STP since LDPE showed little interaction with RS, as seen in Figure 3. The stronger interface bond was attributed to physical interactions between LDPE and STP at high temperature and high shear extrusion circumstances, as well as chemical reactions between STP and -OH groups RS. As seen in the section above, blends with improved tensile properties arise from improved RS and LDPE adhesion.

Table 3 Thermal properties o LDPE/RS blends

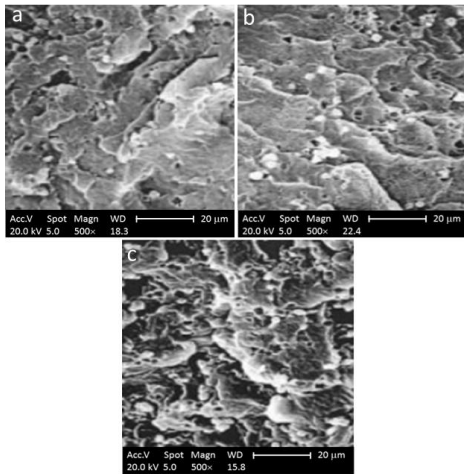| RS content (wt%)	Crystallization temperature (T_C)		Melting temperature (T_m)	
	LDPE/ RS	LDPE/RS/ STP	LDPE/ RS	LDPE/RS/ STP
V. LDPE	98.5	-	112.9	-
10	97.3	98.2	115.4	114.7
20	96.8	97.3	119.3	118.6
30	96.5	97.1	119.8	119.3
40	95.9	96.5	120.1	119.8

Figure 3 SEM photograghs of fracture surface of LDPE/RS blends with different RS-to-LDPE ratios (w/w) (a) 20%, (b) 30%, and (c) 40%.
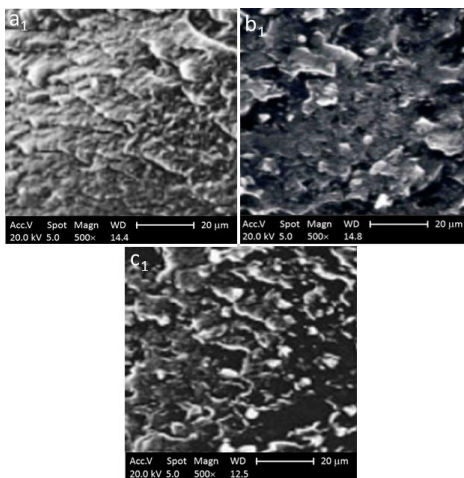

Figure 4 SEM photograghs of fracture surface of LDPE/RS/STP blends with different RS-to-LDPE ratios (w/w) (a₁) 20%, (b₁) 30%, and (c₁) 40%.

3.2.3 Thermal properties

Table 3 provides a summary of the crystallization temperature (T_c) and melting temperature (T_m) of various RS and LDPE blends. Due to the fact that RS was not gelatinized nor melted during extrusion (Figure 3 and 4), T_c and T_m were both LDPE characteristics. With the addition of RS, the T_c of LDPE reduced, which was consistent with research on corn starch with LDPE conducted elsewhere (28). The following two factors may help to explain the detrimental impact

on the crystallization of LDPE from RS. Because LDPE is naturally branching, the addition of RS prevented it from crystallizing, making the crystals that formed when the material was cooled more complicated and less flawless. The second explanation was that the interfacial tension between RS and LDPE prevented the migration and diffusion of long-chain branched polyethylene molecular chains to the crystal surface of short-chain branched polyethylene, which suppressed LDPE crystallization during cooling. In agreement with the corresponding decreasing T_c, the T_m of LDPE in the blends increased as RS concentration increased. Therefore, RS had an impact on LDPE's melting as well as crystallization.
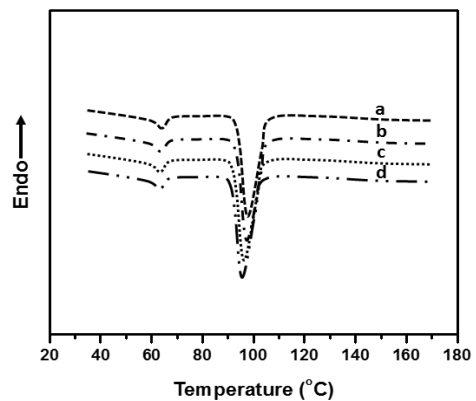

Figure 5 DSC cooling curves for (a) LDPE, (b) LDPE80/RS20 (weight basis), (c) LDPE70/RS30 (weight basis), (d) LDPE60/RS40 (weight basis).
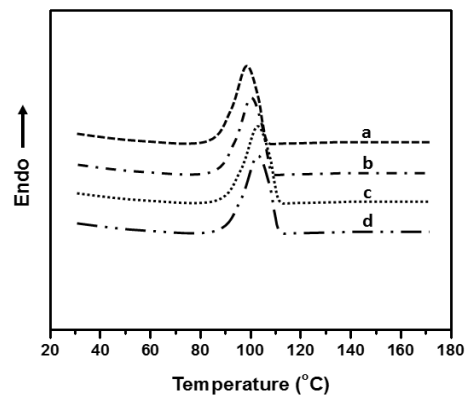

Figure 6 DSC heating curves for (a) LDPE, (b) LDPE80/RS20 (weight basis), (c) LDPE70/RS30 (weight basis), (d) LDPE60/RS40 (weight basis).

The fact that T_c was much higher in blends with STP added than in blends without STP suggested that STP lessened the detrimental effects of RS on the crystallization of LDPE, bringing T_c closer to that of pure LDPE. The trend in T_m, however, was less obvious. This outcome may have been caused by how RS and STP interacted.

3.2.4 Soil burial degradation study

It is theoretically possible for complete polymers to corrode in the right circumstances, independent of their chemical makeup or source. However, a polymer described as "nondegradable" is one that doesn't degrade at all while being used or even after very long-term use (29, 30). Understanding the deterioration performance and kinetics of synthetic LPDE polymers and looking into the kinetics of degradation caused by variations in RS content in polymers were its main points in the degradation research. The composite samples' measured weight before and after deterioration are shown in Table 4, and it was from these measurements that the final weight loss (or deterioration) was estimated.

Table 4. LPDE polymer sample weight (before and after decay) containing different percentages of RS.

A	B	C	D
0	0.485	0.485	0.00
10	0.473	0.473	0.08
20	0.513	0.491	4.21
30	0.551	0.518	6.25
40	0.653	0.596	8.79

A: RS content (wt%); B: Weight (before degradation) (g); C: Weight (after degradation) (g); D: Weight loss (%)

There was no discernible weight loss in virgin LDPE or LDPE with low RS content (e.g., 10% wt%). This outcome is consistent with the idea that virgin LDPE is technically non-corrosive and shouldn't lose weight. Samples of LDPE polymer having over 10% RS should experience some weight loss (e.g., degradation). However, due to temporal restrictions (such as short burial periods), degradation might not be clearly visible. Additionally, the likelihood of RS (10 wt%) contributing to polymer breakdown may be quite minimal. Weight loss of 4.21%, 6.25%, and 8.79% was observed for LDPE polymer samples having 20%, 30%, and 40% RS, respectively. These findings demonstrate that increased RS content increases the kinetics of degradation, which in turn accelerates weight loss. This might be because RS is hydrophilic, which has been taken into account in prior research (31). Because RS is hydrophilic, it absorbs moisture, which leads to the polymer's degradation. The amount of moisture increases with RS content, which causes the composite to deteriorate more quickly. Physical changes in the polymer sample's rough morphology have been noticed, such as the roughening of the surface during the erosion period depicted in Figure 7. Higher surface roughness of samples is a result of enhanced degradation with increased RS concentration. Weight loss and variations in bodily entrance of soil samples (i.e., surface roughness) can be considered as evidence of the perishable of these polymers in landfills or natural environments. The outcomes point out that the inclusion of RS into LDPE increases the hydrophilicity and degradability of the whole polymer. Alike deterioration phenomena of LDPE inclusion with RS have been observed in some other studies (20, 32). Thus, the deterioration properties of RS blended LDPE can be modified by manipulating the RS content in the LDPE matrix. The polymer should be advanced with basically controlled deterioration properties while maintaining the necessary strength of the polymeric ingredient during the designed lifetime for a specific application.
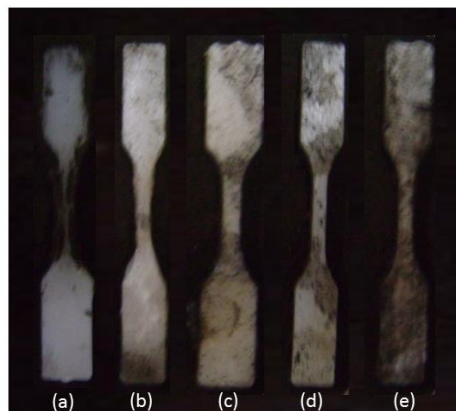

Figure 7 The bodily existence of LDPE composite samples having different proportions of RS later two months lengthy burial which exhibits dissimilar stages of decay: (a) Virgin LDPE, (b) LDPE90/RS10, (c) LDPE80/RS20, (d) LDPE70/RS30, and (e) LDPE60/RS40.

3.2.5 Water absorption investigation

After 30 days of immersion, Figure 8 shows the water uptake as a function of the immersion period for virgin LDPE, LDPE60/RS40, and LDPE55/RS40/STP5 composites. The water uptake rate of LDPE60/RS40 and LDPE55/RS40/STP5 composites was seen to be greater during the first 10 days before normal state saturation occurred. The concentration gradient on the components may be the cause of the decrease in water absorption rate during immersion. Water molecules can quickly fill the composite surfaces and enter the material through the pores, where they are then quickly absorbed by the composite. Because some RS particles were removed from the sample, the water absorption may somewhat decrease as the immersion period increases. It has been hypothesized that when RS particles absorb water, they expand, get larger, and become pushed. It has been noted that LDPE55/RS40/STP5 composites absorb less water on average than other composites. The quantity of free -OH groups on the surface is decreased and the water absorption percentage is decreased in cross-linked LDPE55/RS40/STP5 composites.
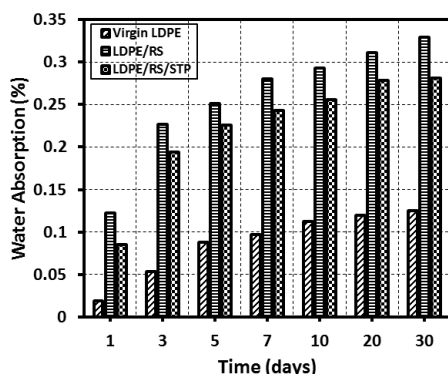

Figure 8 Water uptake values for virgin LDPE, LDPE60/RS40, and LDPE55/RS40/STP5 composites.

4. Conclusions

By incorporating RS and applying processes like STP cross-linker, LDPE polymers have been produced successfully. The entire process gives you the freedom to enhance a wide range of polymers with various mechanical, thermal, corrosion, and water absorption properties. The characterization outcomes show that the variability of the RS content and the proportion of STP cross-linkers is a highly effective way to modify the mechanical, thermal, and corrosion properties of polymers. The strength of the polymer (i.e., tensile modulus) improved with the proportion rise of RS content, STP, whereas the flexibility of the polymer reduced with the rise of the mentioned factors. Results from DSC, SEM, and tensile properties point to the chemical reaction between the hydroxyl groups in RS and the phosphate groups in STP as the cause of the increased compatibility between RS and LDPE. Polymer degradation was increased with increasing RS content. In conclusion, it is possible to modify the properties of LDPE polymers that have RS inserted into them for food packaging applications by adjusting the RS content and modification methods (such as STP crosslinker).

Declaration of conflicting interests

The authors declared that they have no conflicts of interest in the research, authorship, and this article's publication.

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