

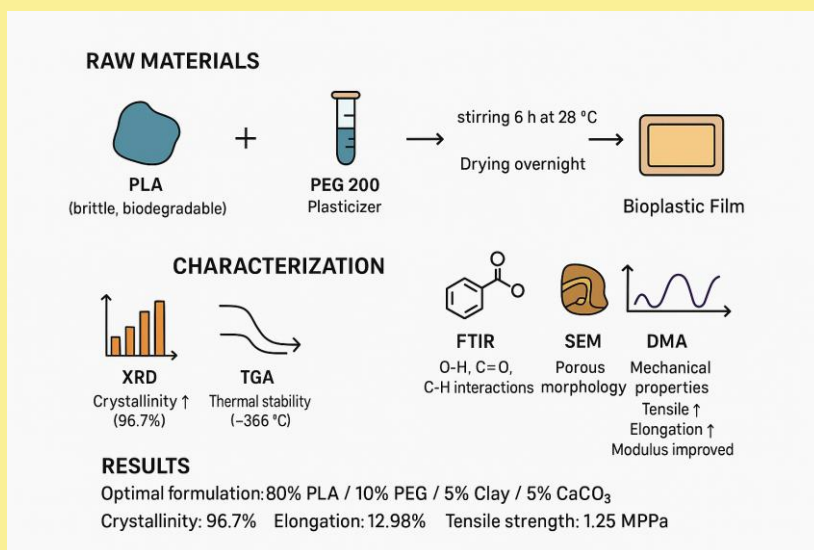
Characterization of Poly Lactic Acid (PLA) Based on PEG-200 Modification of Clay-CaCO₃ as Substitution to LDPE Coating Paper

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Abstract—Plastics play a central role in daily life due to their lightweight nature, mechanical strength, low cost, and durability. Nevertheless, their environmental impact is significant, as they contribute to pollution and global warming. Polylactic Acid (PLA) has gained attention as a biodegradable alternative to conventional LDPE plastics. Although environmentally friendly, PLA exhibits inherent limitations such as brittleness and insufficient toughness, which restrict its broader application. To overcome these drawbacks, plasticizers like Polyethylene Glycol (PEG) 200 and reinforcing agents such as clay and calcium carbonate (CaCO₃) are added to enhance its mechanical performance. This research aims to investigate how these additives affect the resulting film properties. The bioplastic film was produced using a solvent casting method with chloroform as the solvent. The mixture was stirred at ambient temperature for six hours, then cast in a single step into a closed mold and allowed to rest overnight to form a film. The resulting film had a white appearance, slight transparency, and a smooth, slippery surface. Compared to films produced using a layered pouring approach, those formed via the one-pour technique exhibited superior thickness and mechanical strength. To characterize the effects of the additives, several analytical methods were employed: X-Ray Diffraction (XRD) to analyze crystallinity, Thermogravimetric Analysis (TGA) to assess thermal stability, Fourier Transform Infrared Spectroscopy (FTIR) to identify functional groups and chemical bonds, and Dynamic Mechanical Analysis (DMA) to determine mechanical properties such as tensile strength, Young's modulus, and elongation at break. Surface morphology was further examined using Scanning Electron Microscopy (SEM). The most favorable results were observed in the composition containing 80% PLA, 10% PEG, 5% CaCO₃, and 5% clay. This formulation yielded a crystallinity of 96.71%, a decomposition temperature of 366.22 °C, elongation at break of 12.98%, Young's modulus of 56.77 MPa, and a tensile strength of 1.25 MPa. These findings suggest that the film has strong potential as a coating material to replace LDPE.



Keywords—Carboxymethyl Cellulose, Coating Agent, Polyethylene Glycol, Polylactic Acid

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I. INTRODUCTION

Plastic plays a significant role in modern society due to its beneficial properties, including low weight, strength, affordability, and long service life. However, these advantages are accompanied by major environmental challenges. Its non-biodegradable nature, reliance on fossil-based feedstocks, and the release of toxic substances such as dioxins and carbon emissions during combustion contribute to environmental degradation and climate change. According to the Indonesian Aromatic and Plastic Olefin Industry Association (INAPLAS, 2018), Indonesia ranks as the world's second-largest plastic consumer, with an annual usage reaching 64 million tons. There are numerous types of plastic materials used in various industries, each with specific characteristics and applications. For instance, plastics like polyethylene-based variants—both high-density (HDPE) and low-density (LDPE)—are often utilized in packaging due to their flexibility and strength. Meanwhile, polymers such as polypropylene (PP) and polyvinyl chloride (PVC) are widely applied in household products and construction materials. Other examples include polyethylene terephthalate (PET), commonly used in beverage containers, polystyrene (PS) for disposable items, and polycarbonate (PC), known for its toughness and clarity, often used in electronics and safety equipment.

Among biodegradable alternatives, Polylactic Acid (PLA) has received significant attention as it originates from renewable sources, is non-toxic, and can decompose naturally in a relatively short time. These traits make it more environmentally friendly than conventional petroleum-derived plastics. Despite its advantages, PLA exhibits drawbacks such as brittleness and limited toughness, which reduce its suitability for demanding applications. One approach to overcoming these limitations is by incorporating plasticizers. These additives function to reduce the glass transition temperature (T_g), increase material ductility, and enhance the processability of PLA. Previous research shows that mixing plasticizers into PLA matrices has improved their mechanical performance[1]

The addition of plasticizers typically results in a lower T_g and an increase in elongation, which makes PLA films more elastic and easier to shape or modify. However, increasing plasticizer content can also reduce the material's tensile strength and stiffness[2]. To improve mechanical properties without compromising other aspects, reinforcing agents such as fillers can be introduced. Among the available options, clay has shown promise due to its compatibility with PLA and its ability to improve strength characteristics. Studies have revealed that higher concentrations of clay in PLA composites lead to increased tensile strength due to enhanced hydrogen bonding, which strengthens the polymer network and makes it more resistant to deformation[3].

This research aims to investigate the influence of various additives on the characteristics of PLA-based

bioplastic films. The films were fabricated using a solvent casting method, employing chloroform as the solvent. The solution was stirred for six hours at room temperature, poured into a mold in a single step, and allowed to stand overnight until film formation occurred. The resulting films were white, slightly translucent, and had smooth, slippery surfaces.

II. METHOD

A. Research Materials

Poly Lactic Acid (PLA), Poly Ethylene Glycol (PEG) 200 as plasticizer produced by Merck, Germany for Analysis Emsure, Calcium Carbonate (CaCO_3), Liquid Clay produced by NARA, and Chloroform. *Pay attention a significant figure and avoid an unnecessary long digit number.*

B. Research Method

For film making, PLA, PEG 200, Clay, and CaCO_3 were dissolved into Chloroform at room temperature of 28 °C at Erlenmeyer using a magnetic stirrer for 6 hours at 200 rpm until the solution became homogeneous. The homogeneous solution was then poured into a petridish and placed in a laminar flow at room temperature overnight or until the solvent evaporated and formed a film. Weight ratio variation of PLA and PEG 200 starts from 0-40% of PEG 200 with intervals of 20 wt%. And for the variation of the weight ratio of the filler (Clay and CaCO_3) starting from 0-100% of Clay with intervals of 25 wt%.

C. Research Characterization

Dynamic Mechanical Analysis (DMA) is conducted to evaluate mechanical properties such as tensile strength, Young's modulus, and elongation at break in both neat PLA films and PLA-based composite films. The instrument used for this assessment is the Mettler Toledo STARE System DMA/SDTA 861e, with sample dimensions of 9 mm in length, 4 mm in width, and 0.09 mm in thickness.

X-Ray Diffraction (XRD) is utilized to characterize the crystalline structure within the film, distinguishing between crystalline and amorphous regions. This technique allows for the determination of lattice parameters and estimation of particle size. The degree of crystallinity is calculated by comparing the area under the crystalline diffraction peaks with the total diffraction area. The analysis is carried out using the X'PERT PRO Diffractometer at a controlled temperature of 25 °C.

Fourier Transform Infrared Spectroscopy (FTIR) is used to identify molecular vibrations and analyze both organic and inorganic compounds. This method supports qualitative and quantitative evaluation of chemical groups in the film by examining absorption intensities at specific wavelengths. The FTIR analysis is performed with an Agilent Technologies spectrometer, using 16

scans per sample over a wavenumber range of 4000 to 650 cm^{-1} .

Thermogravimetric Analysis (TGA) is employed to examine the thermal stability of the film by tracking changes in mass relative to increasing temperature and time. The procedure is carried out using a Mettler Toledo STARe SW 10.00, operating from 26 °C to 600 °C at a heating rate of 10 °C per minute under an air atmosphere.

Scanning Electron Microscopy (SEM) was used to examine the surface morphology of the bioplastic films. This technique provides detailed visualization of the film's surface structure, including fiber formation, distribution of fillers, roughness, and porosity. Prior to imaging, the film samples were cut into appropriate sizes and coated with a thin layer of conductive material (such as gold or platinum) using a sputter coater to prevent charging during analysis. The surface morphology was then analyzed using a Scanning Electron Microscope operating under high vacuum at an appropriate accelerating voltage. SEM micrographs were captured at various magnifications to observe the dispersion and compatibility of the additives within the PLA matrix.

D. Research Variables

Variables that were used in this research are showed in Table 1.

TABLE 1.
VARIABLE LIST

Variable type
100%PLA
80%PLA/20%PEG
80%PLA/10%PEG/10%CaCO ₃
80%PLA/10%PEG/7,5%CaCO ₃ /2,5%Clay
80%PLA/10%PEG/5%CaCO ₃ /5%Clay
80%PLA/10%PEG/2,5%CaCO ₃ /7,5%Clay
80%PLA/10%PEG/10%Clay
60%PLA/40%PEG
60%PLA/20%PEG/20%CaCO ₃
60%PLA/20%PEG/15%CaCO ₃ /5%Clay
60%PLA/20%PEG/10%CaCO ₃ /10%Clay
60%PLA/20%PEG/5%CaCO ₃ /15%Clay
60%PLA/20%PEG/20%Clay

III. RESULTS AND DISCUSSION

A. PLA Films Preparation

Based on physical observations by naked eye, 100%PLA, 80%PLA/20%PEG, 60%PLA/40%PEG, 80%PLA/10%PEG/5%Clay/5%CaCO₃, 60%PLA/20%PEG/10%Clay/10%CaCO₃ has a white color and is slightly transparent with a smooth and slippery surface texture and there is no visible difference in color from color or texture between one specimen and another. However, if the specimen is held with 100%PLA, 80%PLA/20%PEG, 60%PLA/40%PEG (without the addition of fillers in the form of clay and CaCO₃), there is a difference in strength compared to specimens with the addition of filler

(80%PLA/10%PEG/5%Clay/5%CaCO₃) and 60%PLA/20%PEG/10%Clay/10%CaCO₃.

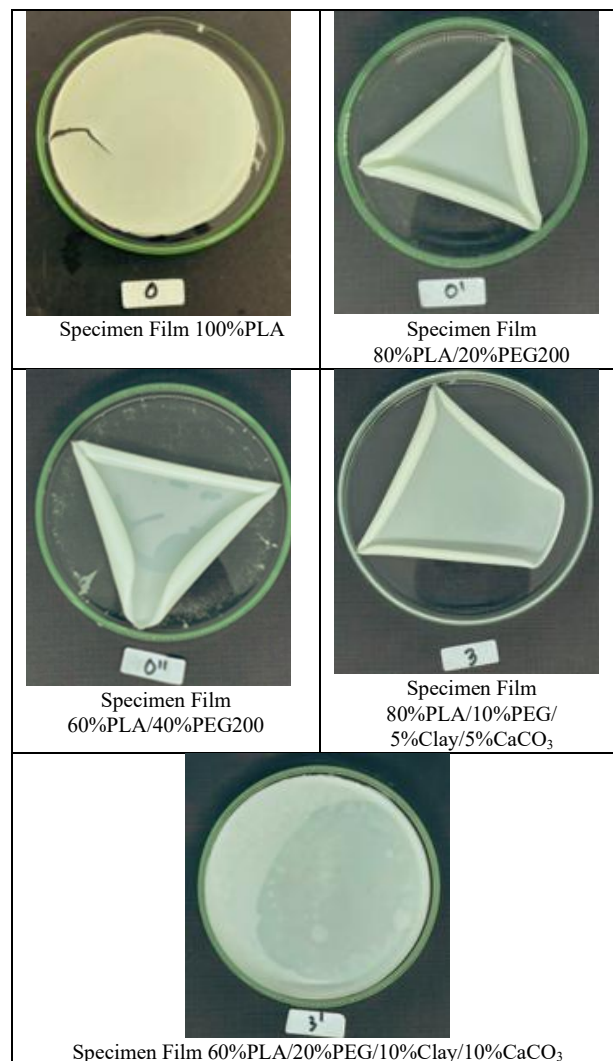


Figure 1. Visual Result of Composite Film

Specimens with a composition of 100%PLA, 80%PLA/20%PEG, 60%PLA/40%PEG (without the addition of filler) are more prone to brittleness and fracture. In contrast to the variable specimens that have undergone filler addition (80%PLA/10%PEG/5%Clay/5%CaCO₃ and 60%PLA/20%PEG/10%Clay/10%CaCO₃) which has greater elasticity, if held and pulled has a greater tensile strength and is not easily brittle and broken. This is in accordance with the literature study that pure PLA has brittle, brittle and inelastic properties so that it is necessary to add fillers and plasticizers to improve the mechanical properties of PLA[4].

B. X-Ray Diffraction

Characterization using XRD aims to determine the degree of crystallinity of the film and showed it value in Table 2. Based on Fernanada's research, 2017, the higher the crystallinity value, it indicates that the mixing composition in a material is more fully dispersed. This will affect the strength properties of a material. Based on the

XRD graph in Figure 2. and the calculation results in Table 2.

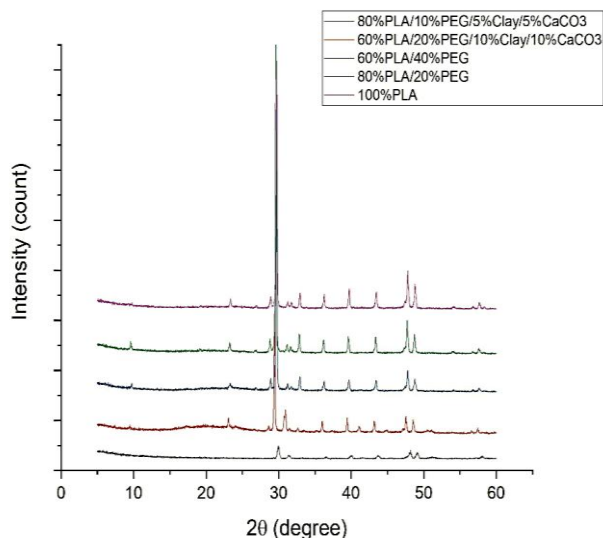


Figure 2. Graph of XRD samples of (a) 80%PLA/10%PEG/5%Clay/5%CaCO₃, (b) 60%PLA/20%PEG/10%Clay/10%CaCO₃, (c) 60%PLA/40%PEG, (d) 80%PLA/20%PEG, (e) 100%PLA

Based on the XRD graph in Figure 2 and the calculation results in Table 2, it can be observed that the degree of crystallinity varies depending on the composition of PLA, PEG, clay, and CaCO₃

$$\%Crystallinity = \frac{\text{Area of Crystalline Peaks}}{\text{Area of All Peaks (Crystalline + Amorphous)}} \times 100\%$$

TABLE 2.
CRYSTALLINITY (%) VALUE

Material	Crystallinity (%)
100%PLA	43.18
80%PLA/20%PEG	28.83
80%PLA/10%PEG/10%CaCO ₃	44.73
80%PLA/10%PEG/7,5%CaCO ₃ /2,5%Clay	22.56
80%PLA/10%PEG/5%CaCO ₃ /5%Clay	96.71
80%PLA/10%PEG/2,5%CaCO ₃ /7,5%Clay	93.35
80%PLA/10%PEG/10%Clay	34.17
60%PLA/40%PEG	23.47
60%PLA/20%PEG/20%CaCO ₃	3.95
60%PLA/20%PEG/15%CaCO ₃ /5%Clay	84.49
60%PLA/20%PEG/10%CaCO ₃ /10%Clay	86.31
60%PLA/20%PEG/5%CaCO ₃ /15%Clay	71.71
60%PLA/20%PEG/20%Clay	37.20

The addition of plasticizer reduces the crystallinity of the mixture. This decrease in crystallinity value occurs due to the influence of the addition of a plasticizer which serves to increase the elongation strength with the side effect of decreasing the tensile strength value. This decrease in tensile strength is indicated by a decrease in the value of the existing crystallinity. Based on previous literature studies, it has been studied that PLA has brittle properties and is difficult to form, characterized by high

tensile strength and low elongation strength. This causes the need for plasticizing agents to make PLA flexible and malleable. However, the addition of a plasticizer will significantly reduce the tensile strength value, this also has a negative impact on the mechanical properties of PLA[5]. So it is necessary to add filler agents, one of which is clay and CaCO₃ to improve the mechanical properties of the PLA by increasing the tensile strength without reducing the elongation strength.

C. Thermogravimetric Analysis (TGA)

Figure 3 showed that the 100%PLA variable has a decomposition temperature ranging from 371.45 °C, in the 80%PLA/20%PEG variable at a temperature of 366.67 °C, 60%PLA/40%PEG at a temperature of 366.67 °C, temperature 367.25 °C, 80%PLA/10%PEG-/5%CaCO₃/5%Clay at a temperature of 366.22 °C and at a variable 60%PLA/20%PEG-/10%CaCO₃/10%Clay at a temperature of 365.82 °C.

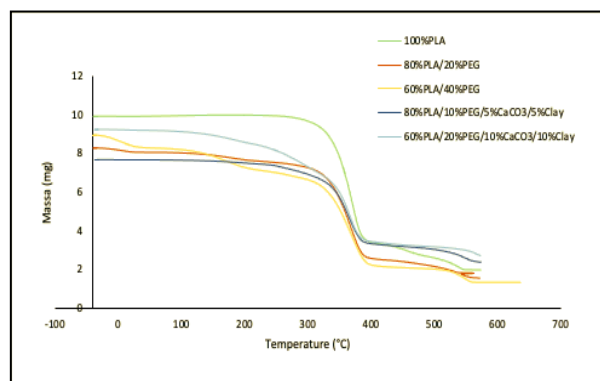


Figure 3. TGA Analysis Result

Figure 3. shows that the addition of CaCO₃ and Clay lowers the decomposition temperature when compared to the blank variable or 100% PLA. When compared between the variables 80%PLA/10%PEG/5%CaCO₃/5%Clay with 60%PLA-/20%PEG/10%CaCO₃-/10%Clay, the temperature decomposed at the variable 60%PLA-/20%PEG /10%CaCO₃/10%Clay becomes lower, so overall the addition of additives in the form of plasticizers and fillers can reduce the decomposition temperature of the film. The addition of additives also increases the composite residue at high temperatures. This is thought to be caused by changes in the polyblend structure during mixing[6]. So it can be concluded from the TGA analysis test chart above that the addition of additives can reduce the temperature of decomposition but the decrease is not significant so that additives can still be added. Based on a literature study according to Yusof (2018)[7], LDPE plastic will decompose at a temperature of 394.74°C. This shows that the decomposition temperature of LDPE plastic is not much different from that of PLA film with the addition of filler and plasticizer.

D. Fourier Transform Infrared Spectroscopy (FTIR)

The incorporation of PEG into PLA blend films can be confirmed through the FTIR spectra shown in Figure 4. In pure PLA (a), the characteristic peaks are dominated by the stretching vibrations of C=O at $\sim 1750\text{ cm}^{-1}$ and C-H at $\sim 2995\text{--}2945\text{ cm}^{-1}$, without the appearance of hydroxyl-related peaks. However, when PEG is added, as in (b) 80%PLA/20%PEG and (c) 60%PLA/40%PEG, new absorption bands emerge around $3414\text{--}3399\text{ cm}^{-1}$, which are absent in neat PLA. These peaks correspond to O-H stretching vibrations, indicating the presence of PEG and possible hydrogen bonding interactions. The intensity of these O-H peaks increase with PEG concentration, confirming that higher PEG loading enhances intermolecular interactions.

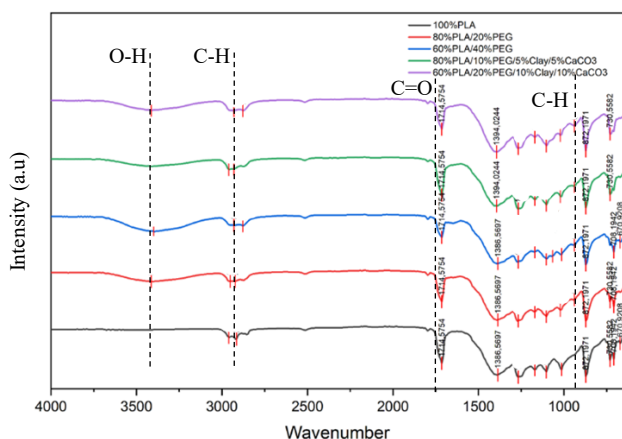


Figure 4. Spektra FTIR Spesimen (a) 100%PLA, (b) 80%PLA/20%PEG, (c) 60%PLA/40%PEG, (d) 80%PLA/10%PEG/5%Clay/5%CaCO₃, (e) 60%PLA/20%PEG/10%Clay/10%CaCO₃

In contrast, in formulation (d) 80%PLA/10%PEG/5%Clay/5%CaCO₃, the hydroxyl peaks at $\sim 3414\text{ cm}^{-1}$ are not observed. This is likely due to the relatively low PEG concentration (10%), insufficient to generate a distinct O-H absorption band compared to blends containing 20% or 40% PEG. A similar trend was reported by Chieng (2014) [2], who found O-H peaks around 3417 cm^{-1} in PLA/PEG blends.

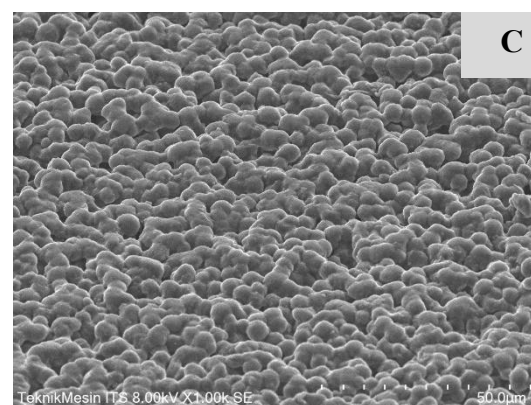
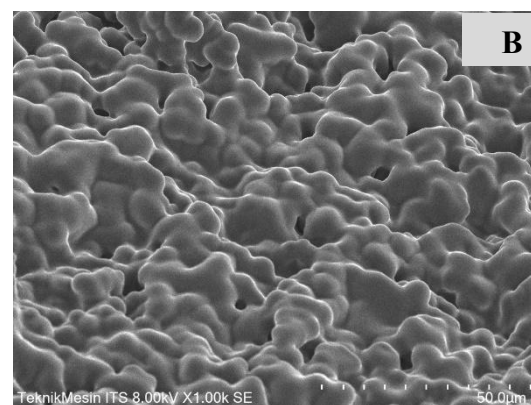
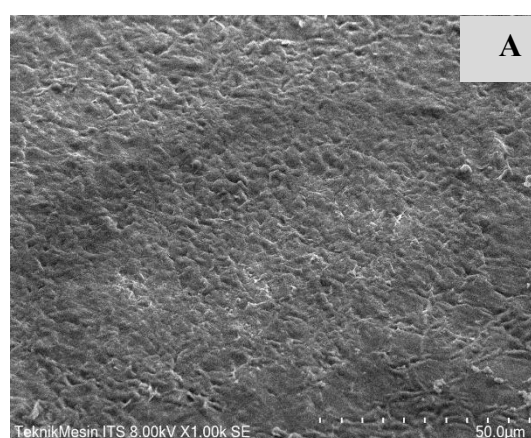
Moreover, a new absorption band at $\sim 939\text{ cm}^{-1}$ (C-H bending) is observed in spectra (b), (c), (d), and (e), confirming PEG incorporation into the blends. This band suggests molecular interaction between PLA and PEG chains. In formulations (d) and (e), which also contain clay and CaCO₃, a decrease in absorption intensity is evident in the $670\text{--}730\text{ cm}^{-1}$ region. This reduction is attributed to the disruption of hydrogen bonding in C-H groups, caused by the incorporation of inorganic fillers. The fillers likely interact with carbonyl groups (C=O) via hydrogen bonding, further supporting synergistic interactions between PLA, PEG, and inorganic particles [8][9].

Overall, the FTIR spectra demonstrate that increasing

PEG concentration enhances hydrogen bonding interactions, while the presence of clay and CaCO₃ modifies the hydrogen bonding network by competing with PEG and PLA for bonding sites.

E. Scanning Electrone Microscope (SEM)

SEM analysis was carried out at five specimens with point selected, 100%PLA, 80%PLA/20%PEG, 60%PLA/40%PEG, 80%PLA/10%PEG/5%CaCO₃/5%Clay, and 60%PLA/20%PEG/10%CaCO₃/10%Clay using 1000X magnitude. Figure 5 shows the SEM of the fractured surface of the film with various compositions. The morphology of the 100% PLA film without any modification shows a smooth and not hollow structure as shown in Figure 5.A.



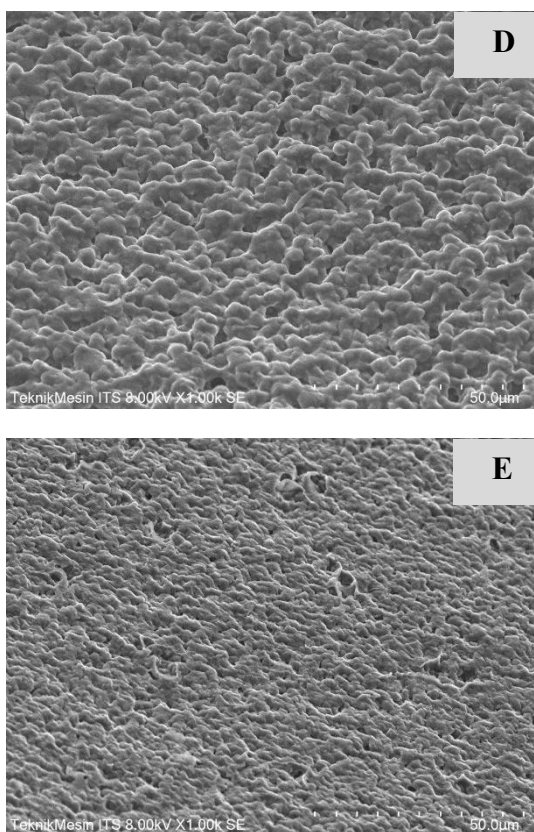


Figure 5. SEM analysis of specimen (A) 100% PLA, (B) 60%PLA/40%PEG, (C) 80%PLA/20%PEG, (D) 60%PLA/20%PEG/10%CaCO₃/10%Clay, (E) 80%PLA/10%PEG/5%CaCO₃/5%Clay, with all specimen was analyzed used 1000X magnitude.

After the addition of 40% and 20% wt PEG as shown in Figure 5.B and C, the morphology of PLA showed more porous with 40% addition PEG. It is also happened in Figure 5.D and E that addition more PEG made PLA have more porous surface than using a few amounts of PEG and none. These effect of filler addition (Clay and CaCO₃) showed in Figure 5.D and E, that using more filler composition made PLA has a more porous surface. Using filler also made PLA surface smoother than have not used filler. SEM analysis was carried out at five specimens with point selected, 100%PLA, 80%PLA/20%PEG, 60%PLA/40%PEG, 80%PLA/10%PEG/5%CaCO₃/5%Clay, and 60%PLA/20%PEG/10%CaCO₃/10%Clay using 1000X magnitude. Figure 5 shows the SEM of the fractured surface of the film with various compositions. The morphology of the 100% PLA film without any modification shows a smooth and not hollow structure as shown in Figure 5.A. After the addition of 40% and 20% wt PEG as shown in Figure 5.B and C, the morphology of PLA showed more porous with 40% addition PEG. It also happened in Figure 5.D and E that addition more PEG made PLA have more porous surface than using a few amounts of PEG and none. Thsese effect of filler addition (Clay and CaCO₃) showed in Figure 5.D and E, that using more filler composition made PLA has a more porous surface. Using filler also made PLA surface smoother than

have not used filler. As was the case in the study[9], the addition of a compatibilizer as PEG200 significantly changed the morphology of the PLLA, creating a homogeneously distributed porous structure in the PLLA matrix. The porous become more clear and more hollow with the addition of CaCO₃, This is following the statement (wanatabe, et al., 2009)[10] that CaCO₃ particles are hollow vaterite particles commonly used in high-class applications, namely as fillers, granules, and additives in the food and pharmaceutical industries. In addition, this porous structure may be suitable as a scaffold in tissue engineering because the film contains biomaterials. PEG content facilitated pore formation, which may have resulted in larger pore formation with higher PEG-containing scaffolds[11][12]. The pore sizes obtained are those used by Porogen and are within the optimal pore size range for bone tissue engineering[13][14][11]. Further investigations related to applications in the biomedical field must be carried out. The addition of filler agents such as clay and CaCO₃ not only improves the tensile strength but also influences the surface morphology of PLA films. SEM observations indicate that filler incorporation reduces surface smoothness due to the formation of micro- and nano-scale domains, which increase surface roughness and porosity. This enhanced porosity may facilitate better interaction and dispersion of the fillers within the PLA matrix, while excessive filler content could lead to agglomeration, resulting in irregular surface features. Conversely, moderate filler loading produces a relatively smoother and more homogeneous surface morphology, which correlates with improved mechanical performance.

F. Dynamic Mechanical Analysis (DMA)

Table 3 showed the DMA analysis results. It can be seen that the 100% PLA specimen has a % strain when the specimen elongates (elongation at break) of 11%, then the addition of a plasticizer in the form of Poly Ethylene Glycol (PEG) 200 as much as 20 wt% makes the specimen have elongation at break 11.56%, 40 wt% PEG 200 has a breaking point of 1.61 %, the addition of 10% PEG/5% Clay/5%CaCO₃ has an elongation at break of 12.98%, 20% PEG/10% Clay/ 10% CaCO₃ has an elongation at break of 4.82%, and the comparison specimen, namely 'Indomaret' commercial plastic bags, has a strain when the specimen breaks of 4.52%.

TABLE 3.
DMA ANALYSIS RESULT

Specimen	Elongation at Break (%)	Modulus Young (Mpa)	Tensile Strength (Mpa)
100%PLA	10.98	83.38	1.07
80%PLA/20%PEG	11.56	66.50	0.80
60%PLA/40%PEG	1.61	16.60	0.18
80%PLA/10%PEG/5%Clay/5%CaCO ₃	12.98	56.77	1.25
60%PLA/20%PEG/10%Clay/10%CaCO ₃	4.82	5258.80	1.32
Commercial plastic	4.52	38.94	1.38

Table 3. it also shows that 100% PLA has a young modulus of 83.38 Mpa, the addition of 20 wt% PEG has a young modulus of 66.5 Mpa, the addition of 40 wt% PEG200 has a young modulus of 16.6 MPa, the addition of 10 wt% PEG, 5 wt% Clay, 5 wt% CaCO₃ has a young modulus of 56.77 Mpa, the addition of 20 wt% PEG, 10 wt% Clay, 10 wt% CaCO₃ has a young modulus of 5258.8 Mpa, and the comparison specimen is the 'Indomaret' commercial plastic bag of 38.94 Mpa. However, in testing on specimens with a composition of 60% PLA/20% PEG/10% Clay/10% CaCO₃ the data and analysis results obtained are still not valid or appropriate because the specimen sample during testing experienced a shift causing the data to be inaccurate.

100% PLA specimen has a tensile strength of 1.07 MPa, then the addition of a plasticizer in the form of 20 wt% PEG 200 has a tensile strength of 0.8 MPa, the addition of a plasticizer in the form of 40 wt% PEG 200 has a tensile strength of 0.18 MPa, addition of 10 wt% PEG 200, 5 wt% CaCO₃, 5 wt% Clay has a tensile strength of 1.25 MPa, addition of 20 wt% PEG 200, 10 wt% CaCO₃, 10 wt% Clay has a tensile strength of 1.32 MPa, and the comparison specimen, namely 'Indomaret' commercial plastic bag, has a tensile strength of 1.38 MPa. Based on the analysis results, the best tensile strength results are in the specimen 80%PLA/10%PEG/5%Clay-/5%CaCO₃ with a value of 1.25 MPa where the tensile strength is greater than the specimen without the addition of CaCO₃ filler, this indicates that the tensile strength increases with the addition of filler. In general, the addition of filler aims to improve the tensile strength of bioplastics[15][16].

The incorporation of PEG as a plasticizer affects both elongation at break and tensile strength of PLA-based composites. As shown in Table 3, increasing PEG content from 0% to 20% slightly enhances the elongation at break. This improvement occurs because PEG reduces intermolecular interactions between PLA chains, thereby increasing chain mobility and flexibility. However, when PEG loading is further increased to 40%, a significant reduction in elongation is observed. This is attributed to phase separation and poor compatibility between PLA and PEG at high concentrations, which leads to microvoids and structural heterogeneity. These defects act as stress-concentration points, causing premature failure of the film and thus reducing elongation.

The addition of inorganic fillers such as clay and CaCO₃ also alters the stiffness and reinforcement of the PLA matrix. Notably, the specimen containing 60% PLA/20% PEG/10% Clay/10% CaCO₃ exhibits the highest Young's modulus compared to other compositions. This significant increase can be explained by the synergistic reinforcement effect of both clay and CaCO₃ particles. Clay provides a layered structure that restricts polymer chain mobility, while CaCO₃ enhances load transfer and rigidity within the composite. The combined effect results in a highly stiff material, reflected in the elevated Young's modulus. However, such reinforcement often

compromises flexibility, which explains the trade-off observed between stiffness and elongation in these specimens. Overall, the mechanical behavior of PLA/PEG/filler composites is strongly influenced by the balance between plasticization, which enhances flexibility, and filler reinforcement, which increases stiffness. Optimal mechanical properties can only be achieved by carefully controlling the ratio of PEG and fillers to prevent phase separation, maintain homogeneity, and enhance load transfer.

The crystallinity values presented in Table 2 further support this correlation, as higher crystallinity, typically observed in samples with clay and CaCO₃, corresponds to increased stiffness and higher Young's modulus, given that crystalline regions restrict chain mobility and enhance load-bearing capability. Conversely, PEG-rich compositions display lower crystallinity, which initially improves ductility and elongation at break up to 20% PEG due to enhanced chain mobility. However, excessive PEG at 40% further reduces crystallinity and induces phase separation, resulting in a drastic decrease in elongation and tensile strength. The specimen with 60% PLA/20% PEG/10% Clay/10% CaCO₃ demonstrates both relatively high crystallinity and strong filler reinforcement, which explains its significantly elevated Young's modulus compared to other formulations. Overall, the interplay between crystallinity and mechanical properties highlights the critical role of balancing plasticizer and filler contents to achieve desirable mechanical performance.

IV. CONCLUSION

This study demonstrates that the modification of Poly Lactic Acid (PLA) with the addition of Polyethylene Glycol (PEG) 200 as a plasticizer and fillers such as clay and calcium carbonate (CaCO₃) significantly improves the mechanical, thermal, and structural properties of the resulting bioplastic films. Among the tested formulations, the composition of 80%PLA/10%PEG/5%CaCO₃/5%Clay exhibited the most promising performance, with a high crystallinity value (96.71%), adequate thermal stability (366.22 °C), superior tensile strength (1.25 MPa), and increased elongation at break (12.98%).

FTIR and SEM analyses confirmed molecular interaction between PLA and the additives, as well as enhanced surface porosity, making the films potentially suitable for biodegradable coating applications. Compared to pure PLA, the modified films offer improved flexibility and mechanical strength while maintaining decomposition characteristics close to that of conventional LDPE, suggesting their feasibility as a sustainable substitute for LDPE in packaging and coating applications.

V. ACKNOWLEDGMENT

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- [17] biocomposite,” ISBEIA 2012 - IEEE Symp Business, Eng Ind Appl, pp. 473–476, 2012, doi: 10.1109/ISBEIA.2012.6422930.
Indonesian Aromatic and Plastic Olefin Industry Association (INAPLAS). Indonesia Plastic Consumption Report, 2018.

VI. REFERENCES

- [1] J. P. Sitompul, R. Insyani, D. Prasetyo, H. Prajitno, and H. W. Lee, “Improvement of properties of poly(L-lactic acid) through solution blending of biodegradable polymers,” *J. Eng. Technol. Sci.*, vol. 48, no. 4, pp. 430–441, 2016, doi: 10.5614/j.eng.technol.sci.2016.48.4.5.
- [2] B. W. Chieng, N. A. Ibrahim, W. M. Z. W. Yunus, and M. Z. Hussein, “Poly(lactic acid)/poly(ethylene glycol) polymer nanocomposites: Effects of graphene nanoplatelets,” *Polymers (Basel)*, vol. 6, no. 1, pp. 93–104, 2014, doi: 10.3390/polym6010093.
- [3] R. Maryana, M. Anwar, A. Suwanto, S. U. Hasanah, and E. Fitriana, “Comparison Study of Various Cellulose Acetylation Methods from its IR Spectra and Morphological Pattern of Cellulose Acetate as a Biomass Valorisation,” *Nat. Environ. Pollut. Technol.*, vol. 19, no. 2, pp. 669–675, 2020, doi: 10.46488/NEPT.2020.V19I02.021.
- [4] Ö. Süfer, “Poly (Lactic Acid) Films in Food Packaging Systems,” *Food Sci. Nutr. Technol.*, vol. 2, no. 4, 2017, doi: 10.23880/fsnt-16000131.
- [5] K. J. Jem and B. Tan, “The development and challenges of poly (lactic acid) and poly (glycolic acid),” *Adv. Ind. Eng. Polym. Res.*, vol. 3, no. 2, pp. 60–70, 2020, doi: 10.1016/j.aiepr.2020.01.002.
- [6] U. Hasanudin and A. Haryanto, “Palm Oil Mill Effluent Recycling System for Sustainable Palm Oil Industries,” *Asian J. Environ. Biotechnol.*, vol. 2, no. 1, pp. 52–62, 2018.
- [7] A. Mustapha *et al.*, “Characterization of Biocomposite Film Coating for Food Paper Packaging,” *Artic. Int. J. Eng. Technol.*, vol. 7, no. 4, pp. 325–330, 2018.
- [8] W. M. Aframehr, B. Molki, P. Heidarian, T. Behzad, M. Sadeghi, and R. Bagheri, “Effect of calcium carbonate nanoparticles on barrier properties and biodegradability of polylactic acid,” *Fibers Polym.*, vol. 18, no. 11, pp. 2041–2048, 2017, doi: 10.1007/s12221-017-6853-0.
- [9] H. Ni'mah, R. Rochmadi, E. M. Woo, D. A. Widiastih, and S. Mayangsari, “Preparation And Characterization Of Poly(L-Lactic Acid) Films Plasticized With Glycerol And Maleic Anhydride,” *Int. J. Technol.*, vol. 10, no. 3, pp. 531–540, 2019, doi: 10.14716/ijtech.v10i3.2936.
- [10] H. Watanabe, Y. Mizuno, T. Endo, X. Wang, M. Fuji, and M. Takahashi, “Effect of initial pH on formation of hollow calcium carbonate particles by continuous CO₂ gas bubbling into CaCl₂ aqueous solution,” *Adv. Powder Technol.*, vol. 20, no. 1, pp. 89–93, 2009, doi: <https://doi.org/10.1016/j.japt.2008.10.004>.
- [11] H. Mesenchymal *et al.*, “PLA / PEG scaffolds for Tissue Engineering applications : In- Vitro cytocompatibility,” vol. 12, no. 1, pp. 31–36, 2020.
- [12] J. Zuhdan, A. Rohmah, N. Hendriani, H. Ni'mah, S. Nurkhamidah, and T. Widjaja, “Characterization and Comparison of Various Lewis Acid Surfactant Combined Catalyst (LASC) and Their Potential for Polylactic Acid Synthesis by Polycondensation,” *Mater. Sci. Forum*, vol. 1057, pp. 65–70, Mar. 2022, doi: 10.4028/p-s44248.
- [13] K. J. L. Burg, S. Porter, and J. F. Kellam, “Biomaterial developments for bone tissue engineering,” *Biomaterials*, vol. 21, no. 23, pp. 2347–2359, 2000, doi: [https://doi.org/10.1016/S0142-9612\(00\)00102-2](https://doi.org/10.1016/S0142-9612(00)00102-2).
- [14] T. Serra, M. Ortiz-Hernandez, E. Engel, J. A. Planell, and M. Navarro, “Relevance of PEG in PLA-based blends for tissue engineering 3D-printed scaffolds,” *Mater. Sci. Eng. C.*, vol. 38, pp. 55–62, May 2014, doi: 10.1016/j.msec.2014.01.003.
- [15] L. Lismeri, P. M. Zari, T. Novarani, and Y. Darni, “Sintesis Selulosa Asetat dari Limbah Batang Ubi Kayu Cellulose Acetate Synthesis from Cassava Stem,” *J. Rekayasa Kimia dan Lingkungan*, vol. 11, no. 2, pp. 82–91, 2016.
- [16] H. Anuar *et al.*, “Effect of PEG on impact strength of PLA hybrid