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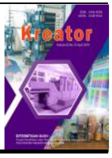

Analysis of the Characteristics and Shelf Life of Multimaterial and Monomaterial Snack Packaging

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ABSTRAK

Peningkatan limbah kemasan fleksibel di Indonesia mendorong pencarian solusi kemasan yang ramah lingkungan. Penelitian ini membandingkan karakteristik fisik, mekanis, dan stabilitas kemasan snack berbasis monomaterial dan multimaterial berukuran 68 gram. Penelitian dilakukan di PT.X menggunakan pendekatan kuantitatif komparatif. Dua struktur kemasan diuji, yaitu OPP/ink/PE/VMBOPP/Resin PP (monomaterial) dan OPP/ink/PE/VMPET/CPP (multimaterial). Parameter yang diuji meliputi WVTR, O_2TR, tensile strength, sealing strength, bonding strength, dan COF. Pengujian dilakukan selama 7 minggu pada suhu oven 80°C, disetarakan dengan penyimpanan 3 tahun pada suhu ruang. Hasil menunjukkan kemasan monomaterial memiliki performa yang kompetitif, terutama pada nilai WVTR dan tensile strength, walaupun nilai O_2TR masih lebih tinggi. Kemampuan daur ulangnya menunjukkan potensi besar dalam mendukung kebijakan pengurangan sampah plastik dan pengembangan kemasan berkelanjutan.

ABSTRACT

The increasing volume of flexible packaging waste in Indonesia drives the need for environmentally friendly packaging solutions. This study compares the physical, mechanical, and stability characteristics of monomaterial and multimaterial *snack* packaging, each with a net weight of 68 grams. Conducted at PT. X, the research uses a quantitative comparative approach. Two packaging structures were tested: *OPP*/ink/PE/*VMBOPP*/Resin PP (monomaterial) and *OPP*/ink/PE/*VMPET*/CPP (multimaterial). Parameters tested include WVTR, O_2TR, *tensile strength*, sealing *strength*, *bonding strength*, and *COF*. Samples were conditioned in an oven at 80°C for 7 weeks to simulate three years of room *temperature* storage. Results show that monomaterial packaging performs competitively, particularly in WVTR and *tensile strength*, although its O_2TR is higher. Its recyclability highlights significant potential in supporting plastic waste reduction policies and contributes to the development of sustainable packaging in the *snack* food industry.

1. INTRODUCTION

Flexible packaging is extensively used in the food industry due to its lightweight nature, convenience, and cost efficiency. However, the growing reliance on flexible packaging has contributed to a substantial increase in plastic waste, particularly in Indonesia. According to Waste4Change (2023), of the 244.72 tons of flexible plastic waste generated daily, only 2.99% is successfully recycled. This low recycling rate highlights the urgent need for alternative packaging solutions and a deeper evaluation of packaging materials in terms of their performance, storage stability, and environmental impact

As part of efforts to transition toward a circular economy and in alignment with national regulations, such as Regulation of the Minister of Environment and Forestry of the Republic of Indonesia No. P.75/MENLHK/SETJEN/KUM.1/10/2019, which outlines the roadmap for waste reduction by producers for the period 2020–2029, a target has been set to achieve a 30% reduction in producer-generated waste compared to the projected waste generation in 2029 (Ministry of Environment and Forestry of the Republic of Indonesia, 2019). In addition, the European Plastics Strategy aims that by 2030, all plastic packaging placed on the market should be recyclable or reusable (Kaiser et al., 2021). In response to these initiatives and to reduce waste generation, PT X

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has recently developed monomaterial-based snack packaging. Although monomaterial packaging has the potential to be recycled, it must demonstrate performance comparable to that of multimaterial packaging in terms of stability, physical properties, and mechanical properties.

According to a Technical Report issued by CEFLEX (2020) (Circular Economy for Flexible Packaging), flexible packaging that is considered readily recyclable is primarily based on polyolefin materials, such as mono-PE, mono-PP, and PE/PP blends. The recycling tolerance limit for mono-PP compositions is defined as having a polypropylene (PP) or polyolefin (PO) blend with a polypropylene content exceeding 90% by weight.

A study by Carullo et al. (2023) reported that monomaterial polyolefin packaging exhibits comparable performance to multimaterial packaging in terms of water vapor barrier properties, sealing strength, and bonding strength. Consequently, monomaterial packaging offers added value due to its improved recyclability. Furthermore, Pettersen et al. (2020) concluded that recyclable monomaterial packaging can be used for packaging chicken fillets without compromising shelf life. These findings represent a significant advancement in the packaging industry and highlight the potential of monomaterial packaging to reduce food packaging waste.

The problem addressed in this study is the lack of data on the long-term stability of monomaterial-based snack packaging. Therefore, this study aims to compare the characteristics of monomaterial and multimaterial snack packaging in terms of: barrier stability against water vapor and oxygen (assessed via WVTR and O_2TR tests), interlayer physical strength (assessed via bonding and sealing strength tests), mechanical strength of the film layers (assessed via tensile strength and coefficient of friction tests), and the potential recyclability, evaluated through yield analysis of the packaging structure.

The tests were conducted over a period of seven weeks at an oven temperature of 80°C to simulate accelerated storage, equivalent to approximately three years at room temperature. The data were analyzed using statistical methods, including standard deviation and linear regression, to evaluate changes in packaging properties over time. These steps are expected to determine whether monomaterial packaging can serve as a sustainable and practical alternative for industrial-scale applications.

2. METHOD

This study employed a quantitative approach with a comparative method to analyze the differences in characteristics between monomaterial and multimaterial snack packaging. The samples used were 68-gram packages, each tested for six parameters: sealing strength, bonding strength, water vapor transmission rate (WVTR), oxygen transmission rate (O_2TR), tensile strength, and coefficient of friction (COF).

The study was conducted from February to June 2025. Storage simulation was performed by accelerating the storage time at an oven temperature of 80°C for seven weeks, representing approximately three years of room-temperature storage. Testing instruments and methods followed ASTM standards, namely ASTM F88 for sealing and bonding strength, ASTM F1249 for water vapor transmission rate (WVTR), ASTM D398 for oxygen transmission rate (O_2TR), ASTM D882 for tensile strength, and ASTM D189 for coefficient of friction (COF).

The test data were analyzed statistically using:

a. Mean dan standard deviation

$$\bar{x} = \frac{\sum X_i}{n} \qquad (1)$$

x̄ = The sample mean
X_i= the value in the data distribution
n = Total number of observations

$$\pm SD = \pm\sqrt{\frac{\sum(x-\bar{x})^2}{n-1}} \qquad (2)$$

±SD = sample standard deviastion
X = the value in the data distribution
$\bar{x}$ = The sample mean
n = Total number of observations

b. Linear regression was used to evaluate the trend of changes in characteristics over time

$$y = ax + b \qquad (3)$$

y = value of the dependent variable when the independent variable is zero
x = independent variable
b = y-intercept of the regression line

3. RESULT AND DISCUSSION

a. WVTR (water vapor transmission rate)

Table 1. Mean and standard deviation of WVTR for multimaterial and monomaterial

Number	Shelf life	WVTR (gr/m^2/day)	
		Multimaterial (*OPP*/ink/PE/*VMPET*/CPP)	Monomaterial (*OPP*/ink/PE/*VMBOPP*/Resin PP)
1.	Day 7	0,357891	0,289512
2.	Day 14	0,256871	0,215681
3.	Day 21	0,324657	0,227426
4.	Day 28	0,245691	0,235684
5.	Day 35	0,314567	0,224578
6.	Day 42	0,268549	0,225671
7	Day 49	0,254116	0,214817
mean		0,288906	0,236425
Standard Deviation (SD)		±0,043	±0,026

The average water vapor transmission rate (WVTR) of multimaterial snack packaging was 0.288906 ± 0.043 g/m²/day with a VMPET thickness of <12 µm, while the monomaterial packaging exhibited a WVTR of 0.236425 ± 0.026 g/m²/day with a VMBOPP thickness of <20 µm. A study by Nurani et al. (2017) reported a WVTR of 0.1634 g/m²/day for flexible packaging with the specification OPP20/VMPET12/CPP35 and a WVTR of 0.5 g/m²/day for a VMBOPP 20 µm barrier. These results indicate that the thickness of the barrier layer, whether VMPET or VMBOPP, significantly influences WVTR values; in general, an increase in barrier layer thickness improves the WVTR performance.

WVTR is a critical parameter for snack packaging, as it directly affects the ability of the packaging to maintain product crispness during storage. Lower WVTR values correspond to better moisture barrier performance, thereby helping to preserve the texture and quality of the snack product over time.

b. O_2TR (oxygen transmission rate)

Tabel 2. Mean and standard devisation O_2TR of multimaterial and monomaterial

Number	Shelf life	O_2TR (cc/m^2/day)	
		Multimaterial (*OPP*/ink/PE/*VMPET*/CPP)	Monomaterial (*OPP*/ink/PE/*VMBOPP*/Resin PP)
1.	Day 7	2,187326	31,15844
2.	Day 14	2,175751	31,04465
3.	Day 21	2,168259	30,98967
4.	Day 28	2,126258	30,95468
5.	Day 35	2,104789	30,88485
6.	Day 42	2,108669	30,88989
7.	Day 49	2,104998	30,91544
Mean		2,139436	30,97680
Standard deviation (SD)		±0,036400	±0,09834

The average Oxygen Transmission Rate (OTR) of multimaterial snack packaging was 2.139436 ± 0.0364 cc/m²/day with VMPET thickness < 12 µm, whereas for monomaterial packaging it was 30.97680 ± 0.09834 cc/m²/day with VMBOPP thickness > 12 µm. According to Dutta & Dutta (2016), the OTR of 12 µm VMPET flexible packaging is 0.24598 cc/m²/day. In the study by Labthink (2023), the OTR of 12 µm VMBOPP film was reported as 53.4515 cc/m²/day. These results indicate that the barrier thickness significantly affects OTR values: the thicker the barrier layer, the lower the OTR, which implies better oxygen barrier performance. Snack products are susceptible to becoming limp and rancid. Therefore, packaging with effective barrier properties is necessary to protect snacks from rancidity. Consequently, the OTR value can serve as a critical indicator of a packaging material's ability to preserve snack product quality.

c. *Bonding Strength*

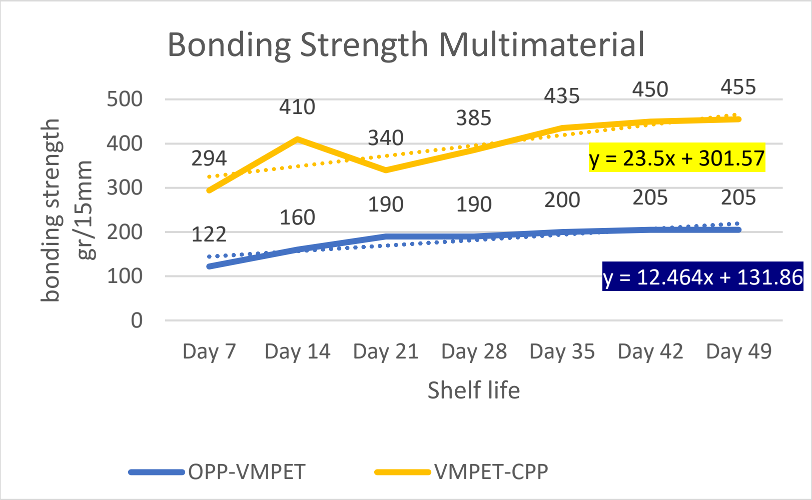

Figure 1. Linier regression graph of *Bonding Strength* Multimaterial

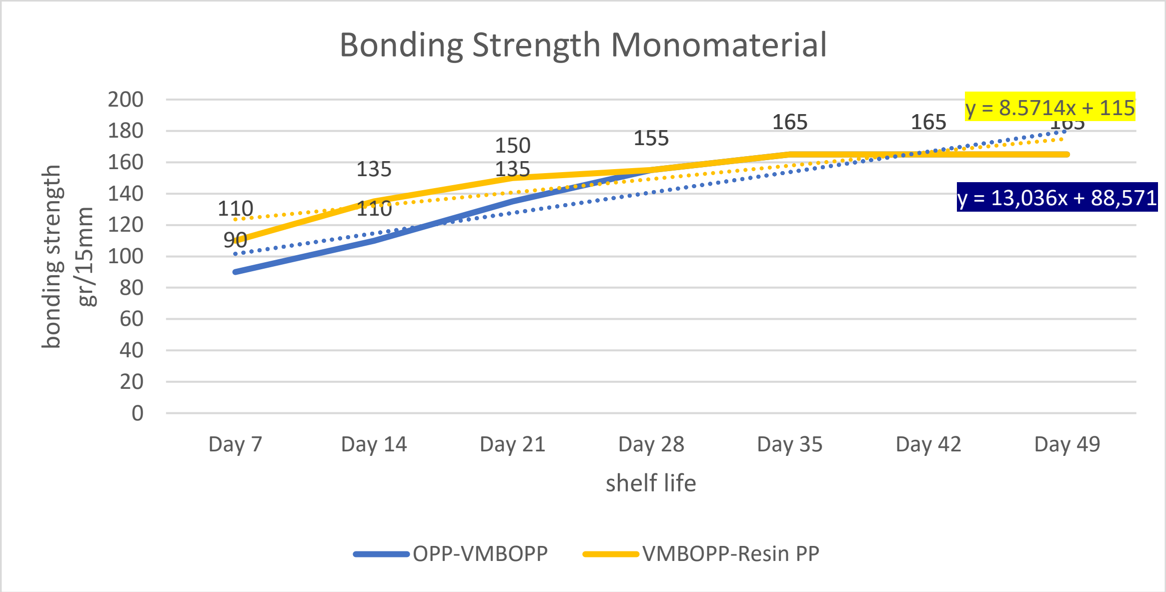

Figure 2. Linier regression graph of *Bonding Strength* Monomaterial

Bonding strength refers to the strength of the adhesion between layers. The linear regression equation for the bonding strength of multimaterial snack packaging layers is 23.5x + 301.57 for the VMPET-CPP layer and 12.464x + 131.86 for the OPP-VMPET layer. Meanwhile, for monomaterial snack packaging, the linear regression equation is 8.5714x + 115 for the VMBOPP-Resin PP layer and 13.036x + 88.571 for the OPP-VMBOPP layer. According to Repeta et al. (2020), the bonding strengths of PET-PP, VMBOPP-PP, and OPP-PP layers are 211.08 g/15 mm, 152.9 g/15 mm, and 216.1 g/15 mm, respectively. The data obtained in this study indicate that the bonding strength of both monomaterial and multimaterial snack packaging decreases over storage time.

d. *Sealing Strength*

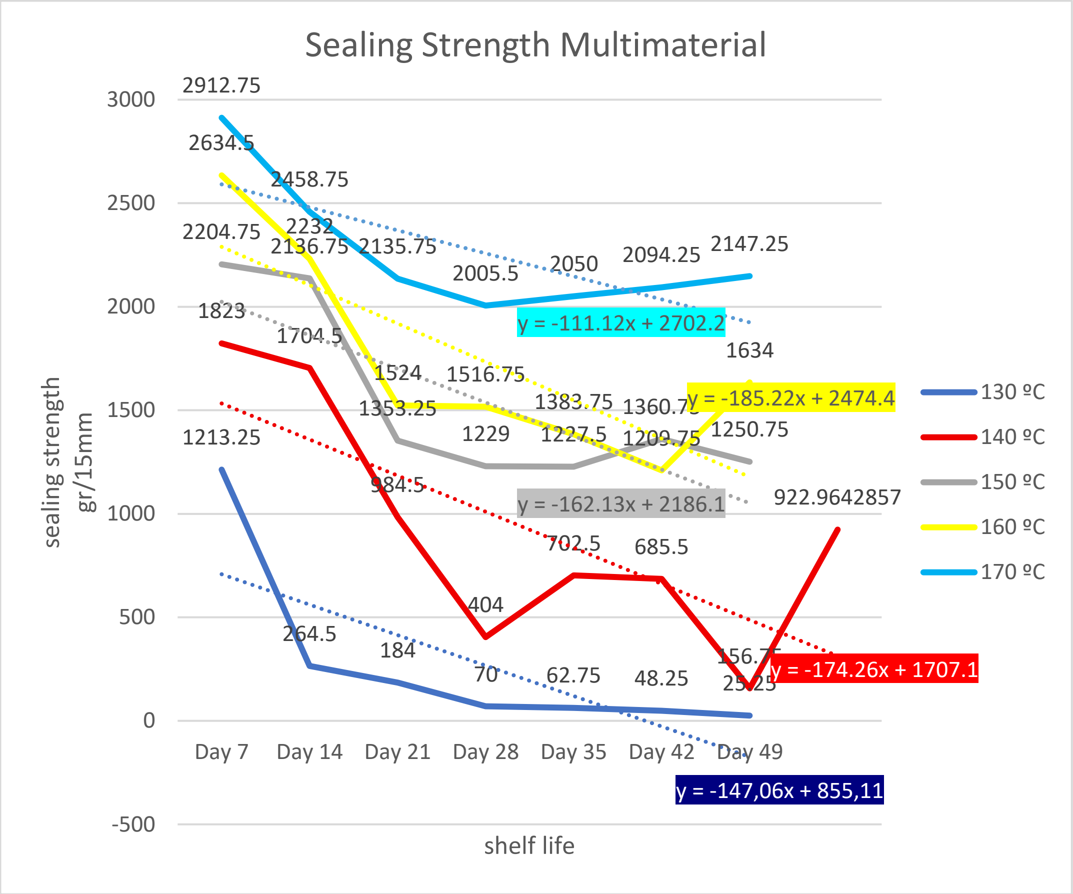

Figure 3. Linier regression graph of Sealing *Strength* Multimaterial

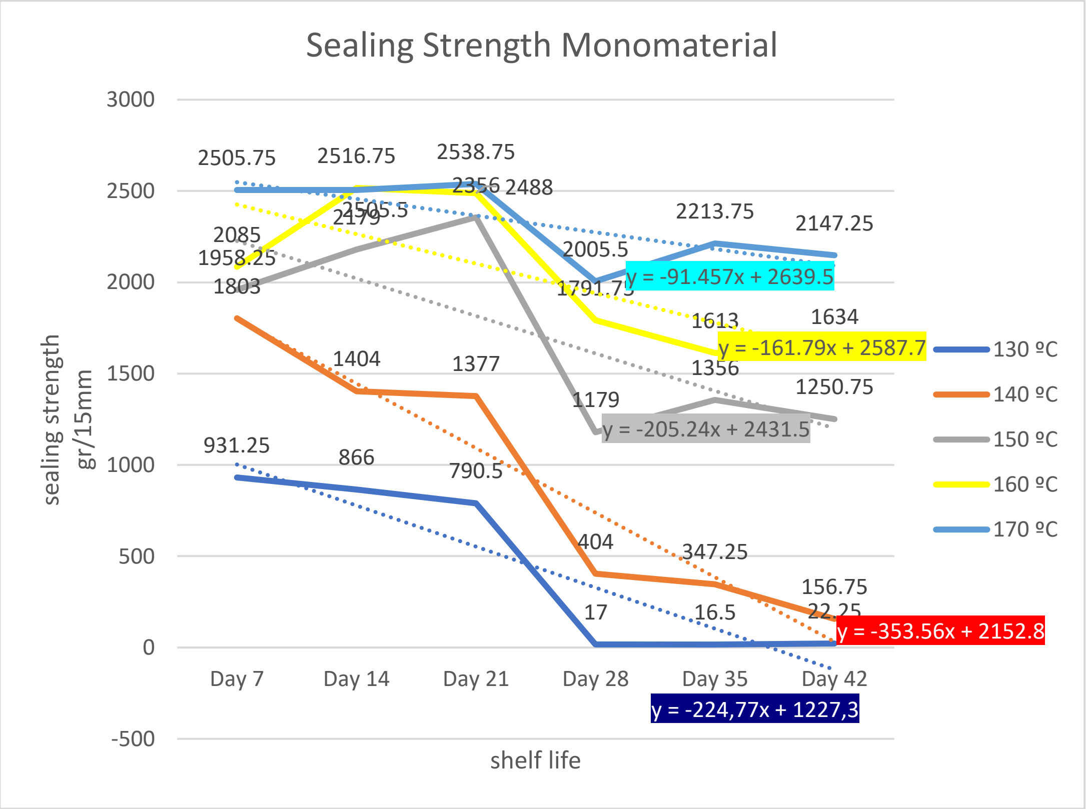

Figure 4. Linier regression graph of Sealing *Strength* Multimaterial

The linear regression equations for multimaterial snack packaging at different temperatures are as follows: -147.06x + 855.11 at 130°C, -174.26x + 1707.1 at 140°C, -162.13x + 2186.1 at 150°C, -185.22x + 2474.4 at 160°C, and -111.12x + 2702.2 at 170°C. For monomaterial snack packaging, the linear regression equations are -184.96x + 1121.1 at 130°C, -302.63x + 2017 at 140°C, -223.79x + 2481 at 150°C, -194.8x + 2675.7 at 160°C, and -124.2x + 2734.8 at 170°C. These results indicate that, for all temperature variations, sealing strength decreases over storage time.

According to Yamada et al. (2017), the sealing strength of OPP-CPP layers was approximately 1700 g/15 mm at 130°C, 1500 g/15 mm at 140°C, 1600 g/15 mm at 150°C, 1650 g/15 mm at 160°C, and 1650 g/15 mm at 170°C. The temperature set by PT. X was 150°C. Although the sealing strength of both multimaterial and monomaterial packaging decreases over storage time, the average sealing strength at 150°C is comparable to previous studies: 1537.5 g/15 mm for multimaterial packaging and 1585.8 g/15 mm for monomaterial packaging.

e. *Tensile Strength*

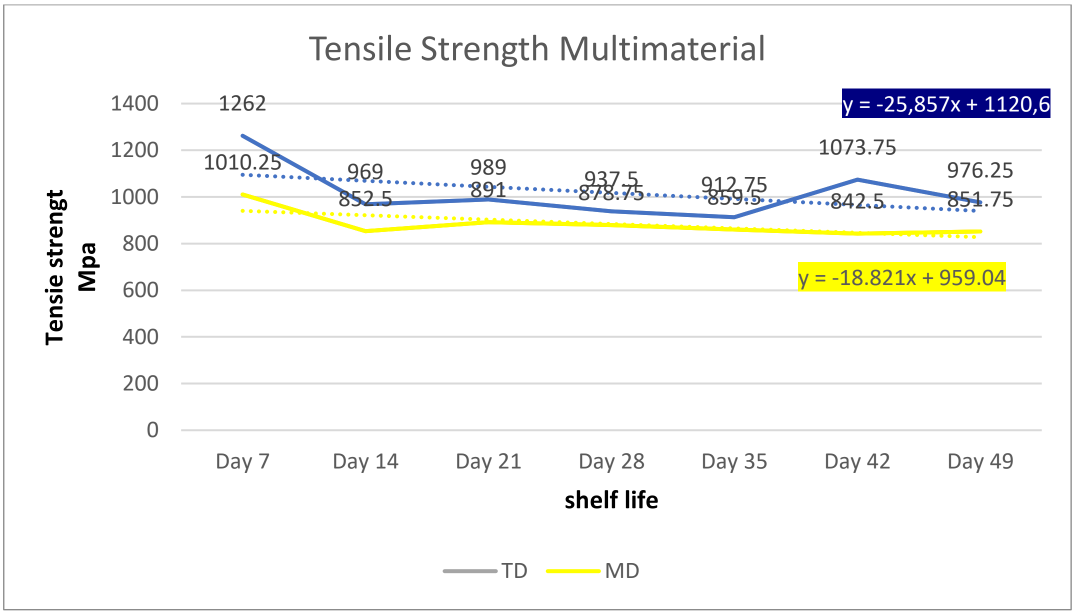

Figure 5. Linier regression graph of *Tensile Strength* Multimaterial

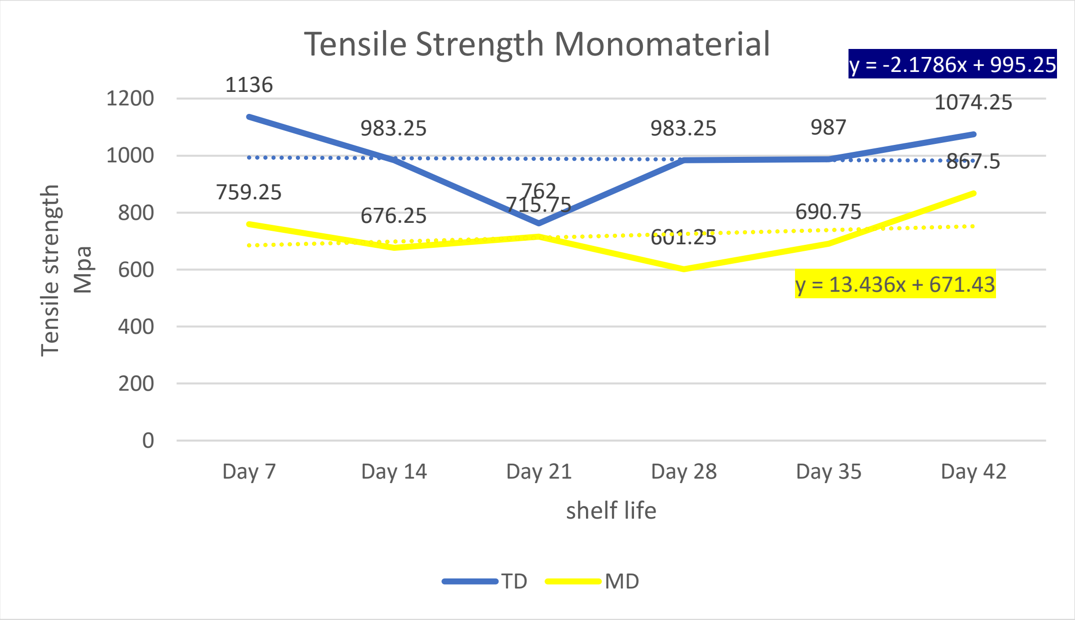

Figure 6. Linier regression graph of *Tensile Strength* Monomaterial

Tensile strength is also influenced by the Machine Direction (MD) and Transverse Direction (TD) (Turriziani et al., 2023). Based on the data obtained, the linear regression equations for tensile strength of multimaterial snack packaging are -25.857x + 1120.6 for TD and -18.821x + 959.04 for MD, with a total thickness of 68–70 µm. For monomaterial snack packaging, the linear regression equations are 1.0625x + 986.61 for TD and -2.4464x + 712.79 for MD, with a total thickness of 76–78 µm. These results indicate that, over storage time, the TD and MD tensile strength of multimaterial snack packaging decreases, whereas the TD tensile strength of monomaterial packaging increases and the MD tensile strength decreases.

f. *COF* (*Coefficient Of Friction*)

Tabel 3. Mean and standard deviation of *COF* multimaterial

Number	Shelf life	*COF*(*Coefficient Of Friction*) Multimaterial									
		In-in		In-out		Out-out		In-met		Out-met	
		static	kinetic	static	kinetic	static	kinetic	static	kinetic	static	kinetic
1	Day 7	0,215	0,190	0,345	0,336	0,278	0,333	0,174	0,182	0,150	0,180
2	Day 14	0,327	0,204	0,382	0,323	0,323	0,434	0,164	0,175	0,155	0,168
3	Day 21	0,364	0,243	0,360	0,310	0,359	0,377	0,245	0,227	0,211	0,225
4	Day 28	0,355	0,245	0,385	0,343	0,392	0,409	0,227	0,209	0,176	0,193
5	Day 35	0,370	0,259	0,391	0,317	0,339	0,328	0,207	0,220	0,160	0,197
6	Day 42	0,318	0,223	0,365	0,376	0,332	0,350	0,202	0,221	0,202	0,212
7	Day 49	0,313	0,219	0,337	0,373	0,339	0,351	0,201	0,219	0,193	0,204
Mean		0,323	0,226	0,366	0,340	0,337	0,347	0,203	0,207	0,178	0,197
Standard deviation(±SD)		0,053	0,024	0,021	0,026	0,036	0,039	0,028	0,021	0,024	0,019

Tabel 4. Mean average and standard deviation of *COF* monomaterial

Number	Shelf life	*COF* (*Coefficient Of Friction*) Monomaterial									
		In-in		In-out		Out-out		In-met		Out-met	
		static	kinetic	static	kinetic	static	kinetic	static	kinetic	static	kinetic
1	Day 7	0,295	0,224	0,492	0,425	0,462	0,358	0,273	0,251	0,281	0,225
2	Day 14	0,283	0,222	0,566	0,457	0,409	0,346	0,240	0,214	0,182	0,200
3	Day 21	0,286	0,233	0,560	0,532	0,300	0,334	0,248	0,220	0,187	0,212
4	Day 28	0,288	0,211	0,563	0,509	0,360	0,319	0,288	0,257	0,227	0,198
5	Day 35	0,291	0,230	0,494	0,438	0,402	0,348	0,246	0,225	0,242	0,219
6	Day 42	0,302	0,220	0,556	0,444	0,372	0,315	0,279	0,269	0,207	0,227
7	Day 49	0,300	0,266	0,527	0,464	0,389	0,335	0,260	0,240	0,222	0,258
mean		0,292	0,229	0,537	0,467	0,370	0,336	0,262	0,239	0,221	0,220
Standard deviation (±SD)		0,007	0,018	0,033	0,039	0,056	0,016	0,018	0,021	0,034	0,020

In this study, several surface tests were conducted to determine the coefficient of friction (COF) for multimaterial snack packaging. The test configurations were as follows: IN-IN represents the CPP surface against CPP, IN-OUT represents CPP against OPP, OUT-OUT represents OPP against OPP, IN-MET represents CPP against the metal on the machine, and OUT-MET represents OPP against the machine metal. The COF values over storage time were as follows: IN-IN, static 0.323 ± 0.053 and kinetic 0.226 ± 0.024; IN-OUT, static 0.366 ± 0.021 and kinetic 0.340 ± 0.026; OUT-OUT, static 0.337 ± 0.036 and kinetic 0.347 ± 0.039; IN-MET, static 0.203 ± 0.028 and kinetic 0.207 ± 0.021; OUT-MET, static 0.178 ± 0.024 and kinetic 0.197 ± 0.019.

For monomaterial snack packaging, the COF test configurations were: IN-IN represents resin PP against resin PP, IN-OUT represents resin PP against OPP, OUT-OUT represents OPP against OPP, IN-MET represents resin PP against the machine metal, and OUT-MET represents OPP against the machine metal. The COF values over storage time were: IN-IN, static 0.292 ± 0.007 and kinetic 0.229 ± 0.018; IN-OUT, static 0.537 ± 0.033 and kinetic 0.467 ± 0.039; OUT-OUT, static 0.370 ± 0.056 and kinetic 0.336 ± 0.016; IN-MET, static 0.262 ± 0.018 and kinetic 0.239 ± 0.021; OUT-MET, static 0.221 ± 0.034 and kinetic 0.220 ± 0.020.

According to Barry A. (2022) in *The Science and Technology of Flexible Packaging*, as cited by Intan et al. (2023), slip classification is defined as follows: low slip (0.410–0.700), medium slip (0.210–0.400), and high slip (0.100–0.200). Based on these criteria, the COF data for multimaterial snack packaging can be categorized as medium slip for both static and kinetic values of IN-IN, IN-

OUT, and OUT-OUT, while IN-MET and OUT-MET are categorized as high slip. For monomaterial snack packaging, COF values for IN-IN, OUT-OUT, IN-MET, and OUT-MET fall into the medium slip category, whereas IN-OUT exhibits low slip for both static and kinetic measurements.

g. Yield of overall packaging structure

Table 5. PO (Poliolefin) content on the yield of layer multimaterial

Layer structure of multimaterial	(yield) (gr/100 cm^2)
OPP	16,38
ink	4
PE (adhesive)	13,77
VMPET	12,6
CPP	22,75
TOTAL	69,5
PE (%)	20%
PP (%)	56%
PO (PE+PP) (%)	76%

Layer structure of monomaterial	*(yield)* (gr/100 cm^2)
OPP	18,2
ink	4
PE (adhesive)	11,0
VMBOPP	13,7
PP	22,55
TOTAL	69,5
PE (%)	16%
PP (%)	78%
PO (%) (PE+PP)	94%

According to a technical report issued by Ceflex (Circular Economy for Flexible Packaging), flexible packaging that is easy to recycle is primarily based on polyolefins, such as mono-PE, mono-PP, and PE/PP blends. The recycling tolerance limit for Mono-PP is defined such that, if the combined PP or polyolefin (PO) mixture accounts for more than 90% by weight, it qualifies for recycling. Based on the calculated weight composition of each snack packaging type, the polyolefin content was found to be 76% for multimaterial packaging and 94% for monomaterial packaging. This indicates that replacing multimaterial snack packaging with monomaterial packaging increases the polyolefin content from 76% to 94%. Therefore, it can be concluded that monomaterial snack packaging is easier to recycle.

4. CONCLUSION

This study demonstrates that the characteristics of monomaterial and multimaterial snack packaging were simulated at an oven temperature of 80°C for approximately seven weeks to accelerate the equivalent of ±3 years of storage. The water vapor transmission rate (WVTR) tests showed that monomaterial packaging has a lower water vapor transmission compared to multimaterial packaging, indicating a superior moisture barrier. Meanwhile, the oxygen transmission rate (O_2TR) was higher for multimaterial packaging.

Regarding bonding strength and sealing strength, monomaterial packaging exhibited stable values comparable to multimaterial packaging, demonstrating that the physical protection function is maintained. For mechanical properties such as tensile strength and coefficient of friction (COF), test results indicate that both types of packaging have relatively similar and consistent performance in terms of strength and slip.

Polyolefin-based monomaterial structures have significant potential as a replacement for multimaterial packaging, which is more difficult to recycle, without compromising technical performance. Therefore, the use of monomaterial packaging can serve as a sustainable solution that supports industry goals in reducing plastic waste and promoting a circular economy.

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6. REFERENSI

ASTM D189. (2014). *Test Method for Static and Kinetic Coefficients of Friction of Plastic Film and Sheeting*. ASTM International. https://doi.org/10.1520/D1894-14

ASTM D882. (2009). *Metode Uji Standar ASTM D882 untuk Sifat Tarik Lembaran Plastik Tipis R&B Inc*. www.onlinedoctranslator.com

ASTM F88. (2009). *Standard Test Method for Seal Strength of Flexible Barrier Materials 1*. www.astm.org,

ASTM F1249. (2020). *Test Method for Water Vapor Transmission Rate Through Plastic Film and Sheeting Using a Modulated Infrared Sensor*. ASTM International. https://doi.org/10.1520/F1249-20

Barry A, M. (2022). *The Science and Technology Of Felxible Packaging*. William Andrew.

Budianto, Y. D. A. H. S. M. Y. (2022). Analisa Pengaruh Temperatur Sealing terhadap Kuat Tarik dan Gugus Fungsi. *JURNAL REKAYASA ENERGI DAN MEKANIKA*, *02*.

Carullo, D., Casson, A., Rovera, C., Ghaani, M., Bellesia, T., Guidetti, R., & Farris, S. (2023). Testing a coated PE-based mono-material for food packaging applications: an in-depth performance comparison with conventional multi-layer configurations. *Food Packaging and Shelf Life*, *39*. https://doi.org/10.1016/j.fpsl.2023.101143

Ceflex (Circular Economy for Flexible Packaging). (2020). *DESIGNING FOR A CIRCULAR ECONOMY Recyclability of polyolefin-based flexible packaging Work*.

Dutta, A., & Dutta, G. (2016). Comparing Optimum Barrier Variables of Aluminium and MPET Foil Based Laminates for Coffee Packaging. In *Journal of Applied Packaging Research* (Vol. 52).

Food Review Indonesia. (2012). *Update on Snack Flexible Packaging*. https://m.foodreview.co.id/blog-56416-Update-on-Snack-Flexible-Packaging.html

Intan, P., Ningrum, P., Mulyasuryani, A., & Febriani, R. (2023). Pengaruh Bahan Aditif Polimer Slip terhadap Karakteristik Film Polietilen. *Ind. J. Chem. Anal*, *06*(01), 75–84. https://doi.org/10.20885/ijca.vol6.iss1.art8

Kaiser, K. M. A., Ginzinger, T., Paolo, F., & Mantia, L. (2021). *Crosslinking Packaging Adhesive and Recycling in a Small-Scale Technical Plant*. *6*, 47. https://doi.org/10.3390/recycling60

Kumar, B., Mishra, N., & Kumar Naik, R. (2017). *Assessment of Some Physical and Mechanical Properties of Different Flexible Packaging Films for Packaging of Tamarind (Tamarindus indica L.) Pulp Briquettes*. https://www.researchgate.net/publication/357998195

Labthink. (2023). *Oxygen permeability: Comparative study of different aluminum-coated films*. https://www.labthinkinternational.com/en-us/literatures/oxygen-permeability-comparative-study-of-different-aluminum-coated-films%20.html

Lubis, S. Y., Tutang[1], P., Siahaan, E., Sobron, M., & Lubis, Y. (2023). Polymer Sealing and Bonding Resistance to the Tensile Strength of Flexible Food Packaging. *International Journal of Innovative Science and Research Technology*, *8*(7). https://doi.org/10.5281/zenodo.8189329

Nurani, D., Sukmadi, I., & Hidayat, N. (2017). *Kualitas Barrier Kemasan Fleksibel Berbasis Metalized Film untuk Produk Pangan Barrier Quality of Flexible Packaging Based on Metalized Film for Food Products*.

Pettersen, M. K., Grøvlen, M. S., Evje, N., & Radusin, T. (2020). Recyclable mono materials for packaging of fresh chicken fillets: New design for recycling in circular economy. *Packaging Technology and Science*, *33*(11), 485–498. https://doi.org/10.1002/pts.2527

Repeta, V., Kukura, Y., Shibanov, V., Myklushka, I., & Kukura, V. (2020). Influence of properties of materials for solventless lamination on the bonding strength of multilayer packaging. *Journal of Print and Media Technology Research*, *9*(3), 177–184. https://doi.org/10.14622/JPMTR-2001

Turriziani, B., Vieira, R., Marangoni Júnior, L., & Alves, R. (2023). Mechanical Recycling of Multilayer Flexible Packaging Employing Maleic Anhydride as Compatibilizer. *Journal of Polymers and the Environment*. https://doi.org/10.1007/s10924-023-03057-9

Yamada, K., Miyata, K., & Kumaresan, R. (2017). A novel methodology for peel strength enhancement of heat-sealed oriented polypropylene/cast polypropylene film by tensile cyclic loading. *Materials Chemistry and Physics*, *187*, 112–118. https://doi.org/10.1016/j.matchemphys.2016.11.054