

CRITICAL EVALUATION OF THE MECHANICAL AND CHEMICAL PERFORMANCE OF THE MULTI-LAYER (PET + POLY) FLEXIBLE PACKAGING LAMINATES**ANKIT BOORA¹, ASHISH JANGIR², BIJENDER³**¹Assistant Professor, Dept. Printing Technology, GJUS&T, Hisar²Scholar, M. Tech, Printing Technology, GJUS&T, Hisar³Assistant Professor, Dept. Printing Technology, GJUS&T, Hisar**ABSTRACT**

Multi-layer flexible packaging has been widely adopted in the food, pharmaceutical and industrial sectors, as it can balance mechanical integrity and barrier properties. Through comprehensive laboratory testing, this study carried out a critical assessment of the mechanical and chemical properties of PET/PE flexible packaging laminates, with a core focus on five core parameters: seal strength, adhesive bond strength, COF, WVTR and OTR. This evaluation conducted two tests to verify the performance of the PET + Poly composite film. Tests recorded an average edge-sealing strength of 19.58 N/15mm, with reliable heat-seal integrity capable of preventing failure during transportation; the average interlayer bonding force was measured at 4.03 N/15mm, indicating sufficient adhesive force. The low standard deviations of both test results confirm that the production process is uniform and stable, substantiating the material's commercial feasibility. This study evaluated the surface behavior of the laminate via measurements of its static and dynamic friction coefficients. The measured average static COF was 0.37 and the average dynamic COF was 0.25. This laminate achieves the optimal balance between processability and packaging stability, is compatible with high-speed packaging and can reduce the risk of slip during storage. This study conducted barrier property tests on the target polymer laminate and completed analysis based on two indicators, WVTR and OTR the measured average WVTR meets the moisture-proof requirements for products with moderate humidity sensitivity OTR test data obtained at different temperatures shows an overall upward trend and the increase in oxygen permeability alongside rising temperature originates from changes in the polymer's intrinsic properties driven by intensified movement of its molecular chains. The PET + Poly composite laminates tested in this study have excellent mechanical strength, stable sealing performance and meet standard moisture resistance requirements. However, their oxygen barrier efficiency decreases significantly in high-temperature environments. This material is suitable for the vast majority of packaging scenarios and only highly oxygen-sensitive products need an additional barrier enhancement layer. This study supplements existing research on the performance characteristics of this material and provides support for the optimization of its specific end-use applications.

Keywords: Flexible Packaging, PET + Poly Laminate, Seal Strength, WVTR, OTR, COF

1.INTRODUCTION

The core iteration of packaging has always revolved around functional upgrades. It developed from a simple carrier that only served to hold items, into a complete system capable of protecting products, extending shelf life, facilitating transportation and boosting consumer convenience. Early packaging primarily used materials including leaves, animal hides, woven baskets and clay containers. In the 20th century, driven by industrialization and macromolecular science (polymer science), soft packaging systems (flexible packaging systems) that consume less material and deliver stronger functionality emerged [1][2]. In the mid-20th century, the emergence of polymeric materials and lamination technology turned flexible packaging into a commercially viable packaging format. Early flexible structures were primarily paper-based laminates. Later, driven by growing demand for three core needs—upgraded product protection, packaging lightweighting and extended shelf life the industry shifted to multi-layer composite plastic films. By incorporating PE, which acts as the heat-seal layer and PET, which serves as the high-strength outer base substrate, the industry developed flexible laminates that combine both mechanical durability and barrier properties [1][3]. PET, developed in the 1940s, has become one of the most widely used packaging polymers, supported by five core properties including tensile strength and dimensional stability [4]. PE was commercialized in the 1930s and achieved widespread adoption after World War II, earning industry preference for four key properties including flexibility and heat sealability [5]. When the two materials are combined into a multilayer

laminates, they form a synergistic packaging material that meets the demands of diverse industries. PET + Poly composite laminates have been applied in four major fields: food, pharmaceuticals, personal care and industrial packaging. PET acts as the outer structural layer, providing mechanical strength, stiffness, thermal stability and printability. The inner polyethylene layer serves as the sealing layer, which delivers flexibility, puncture resistance and gas tightness, enabling manufacturers to balance product protection, packaging integrity, processability and cost-effectiveness [6]. With the growing demand for pre-packaged foods and long-shelf-life products, the assessment of the mechanical and barrier properties of flexible packaging materials has become increasingly important; insufficient seal strength easily leads to leakage, insufficient adhesion causes delamination and abnormal friction coefficients will negatively affect production, stacking and consumer use [7]. Currently, the industry at large has focused on the mechanical properties of packaging, yet barrier performance is the core metric that determines the effectiveness of flexible packaging systems. Water vapor transmission rate (WVTR) and oxygen transmission rate (OTR) are the core evaluation parameters for this performance. The ingress of water vapor and oxygen will trigger various forms of spoilage, so mastering the barrier properties of PET + Poly composite films is a necessary prerequisite for selecting appropriately matched packaging structures [8][9]. Researchers and manufacturers in the flexible packaging field, centered on improving barrier performance and reducing material consumption and environmental impact, are exploring five categories of technologies advanced multi-layer structures, nanocomposite coatings, recyclable single-material laminates, biobased polymers and high-barrier surface treatments. These actors develop fit-for-purpose materials that meet regulatory requirements and follow the principles of the circular economy [10]. Although flexible packaging laminates made from PET and Poly composites have been widely used in industry, they still lack comprehensive assessments of their mechanical and chemical properties. This study will analyze five key indicators, adapt to specific application scenarios, and support the research and development of advanced flexible packaging.

2. RESEARCH METHODOLOGY

To construct the multilayer flexible packaging laminate, Polyethylene terephthalate (PET) and Poly films were utilized. PET was selected for the exterior layer owing to its exceptional mechanical strength, printability and dimensional stability. Poly was chosen for the interior sealant layer due to its strong moisture resistance and heat-sealing capabilities. This PET and Poly composite is frequently employed in food, pharmaceutical and industrial packaging.

The final laminate measured 60 μm in total thickness. The sealing process was performed at 160°C with a sealing pressure of 2.5 bar and a dwell time of 1 second. Prior to testing, all samples were conditioned for 24 hours in an environment maintained at $23 \pm 2^\circ\text{C}$ and a relative humidity of $50 \pm 5\%$. Relevant ASTM standards were then applied to assess seal strength, bond strength, coefficient of friction (COF), water vapour transmission rate (WVTR) and oxygen transmission rate (OTR).

2.2 Methods

2.2.1 Seal Strength

Seal strength test was performed by using a seal strength tester (Lab think C630H Heat Seal Tester), Medford, USA we taken rectangular samples (250mm x 15mm) for seal strength testing at a temperature of 140 degree Celsius and the sealing area is 40mm x 10mm. We applied a sealing pressure of 2.5 bar and a dwell time of 1 second. Now the sealing strength is measured in N/15mm by using the standard ASTM F88.

2.2.2 Bond Strength

A bond strength test was conducted by using a universal testing machine (UTM) (Instron 68TM-10, Boston, MA, USA) by taking a rectangular sample size (250mm x 15mm) with a crosshead speed of 300mm/min. By using the standard ASTM D1876 bond strength test, is used to check the interlayer adhesion, support seal integrity, barrier performance and resistance to mechanical stresses and is measured in N/15mm.

Bond Strength=Force (N)/Sample Width (mm)

2.2.3 Coefficient of friction (COF)

Coefficient of friction (COF) testing was performed by using a COF tester (RDM Test Equipment CF-800XS) according to ASTM D1894 standard. By using rectangular film samples of size 150mm x 63.5mm with the sled area of 63.5mm x 63.5 mm. The test was performed at 24 degrees Celsius and 54 % relative humidity. A standard sled of 200 g mass was placed on the laminate surface and pulled at a speed of 150mm/min. The COF test is carried out to check the critical evaluating machinability, handling characteristics and performance of flexible packaging laminates and the COF test has no unit.

2.2.4 Water vapour transmission rate (WVTR)

water vapour transmission rate (WVTR) was determined using a water permeability tester (Mocon Aqatran 3/34 series) under controlled temperature and relative humidity by mounting a sample with a size of 50cm² by using the ASTM F1249. WVTR test is carried out to check the moisture barrier properties, shelf-life performance and water vapour transmission resistance of multi-layer flexible packaging laminates and expressed in g/m²/day for 24 hours.

2.2.5 Oxygen Transmission rate (OTR)

Oxygen transmission rate (OTR) was measured using an oxygen permeability tester (Mocon OX-TRAN 2/22H) under controlled environment and relative humidity by using a sample size of 50cm². By using the ASTM D3985, the test is carried out for 24 hours to check the product protection ability, oxygen barrier properties and shelf-life performance of multi-layer laminates and the test is measured in cc/m²/day.

3. Result and discussion

3.1 Seal Strength

The seal strength test was performed on PET + Poly laminate to evaluate the sealing performance at various conditioning temperatures of 10°C, 25°C and 45°C. Seal strength is a critical property in flexible packaging as it ensures the package remains properly sealed during storage, handling and transportation.

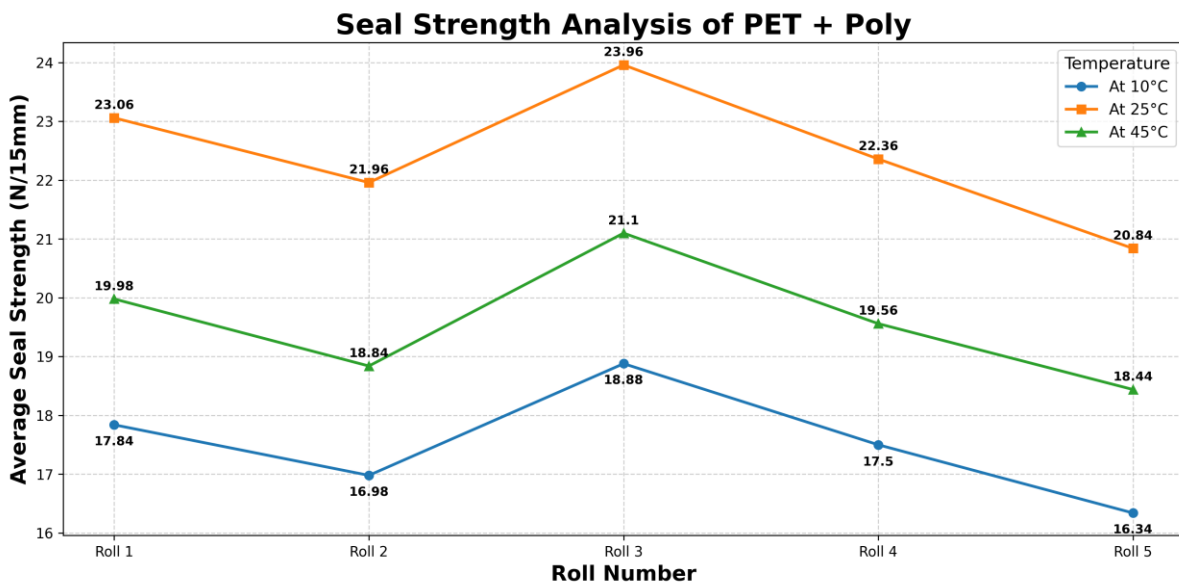


Fig.1.

Seal Strength Analysis of PET + Poly

In this fig.1. indicates that seal strength values were highest at 25°C across all roll samples. Roll 3 exhibited the greatest seal strength, while Roll 5 demonstrated comparatively lower performance. The improved seal formation at 25°C suggests that normal room temperature conditions are more favorable for effective bonding of the sealing layer.

At 10°C, seal strength values decreased for all rolls. This reduction is likely due to the low temperature causing the sealing layer to become slightly rigid, which hinders proper fusion between layers. As a result, the seals formed were comparatively weaker.

At 45°C, seal strength values were moderate. The elevated temperature increased the softness of the Poly layer, enhancing seal formation; however, excessive heat slightly affected sealing uniformity in some samples.

Overall, the PET + Poly laminate exhibited good sealing characteristics across all conditioning temperatures. These results suggest that the laminate can deliver reliable sealing performance for flexible packaging applications that require strong seals and package integrity.

6.2.2 Bond Strength

The bond strength test was conducted on PET + Poly laminate to assess the adhesive bonding performance between the laminate layers at conditioning temperatures of 10°C, 25°C and 45°C. Bond strength is crucial in flexible packaging as it ensures proper adhesion between layers and prevents delamination during handling and storage.

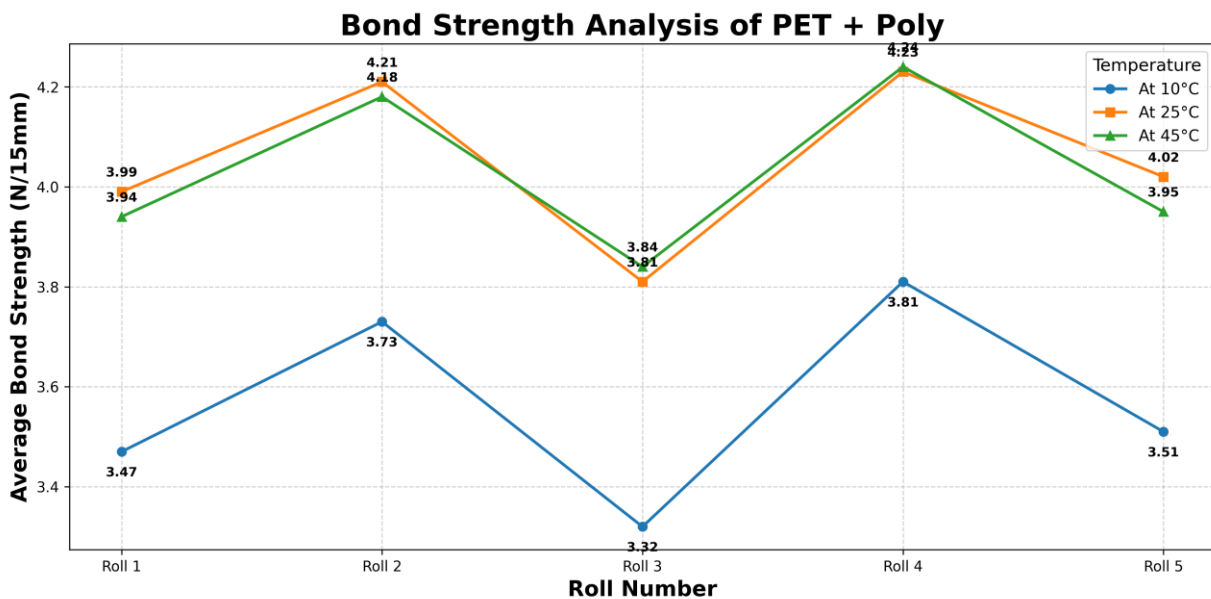


Fig.2.

Bond Strength Analysis of PET + Poly

The fig.2. indicates that bond strength values were relatively higher at 25°C and 45°C. Among the samples, Roll 4 exhibited the highest bond strength, while Roll 3 had comparatively lower values. The improved bonding at 25°C suggests effective adhesive interaction and a stable laminate structure under normal environmental conditions.

At 10°C, bond strength values were generally lower across all rolls. The reduced temperature decreased adhesive flexibility, which slightly hindered the bonding efficiency between the PET and Poly layers, resulting in lower interlayer adhesion.

At 45°C, bond strength values showed a slight increase compared to 10°C. The elevated temperature enhanced adhesive softness and improved bonding between the laminate layers. However, minor variations in values were noted, likely due to differences in coating distribution and laminate uniformity.

The PET + Poly laminate displayed consistent bond strength across all conditioning temperatures. These results suggest that the laminate has strong interlayer adhesion properties and is suitable for flexible packaging applications requiring robust bonding and structural stability.

6.2.3 Coefficient of Friction

The coefficient of friction test was performed on the PET + Poly laminate to examine its surface friction behavior at various temperatures. Both static and dynamic COF values were measured at 10°C, 25°C and 45°C across different roll samples. The coefficient of friction is important in flexible packaging as it influences machine operation, roll movement, slip properties and handling performance during packaging processes.

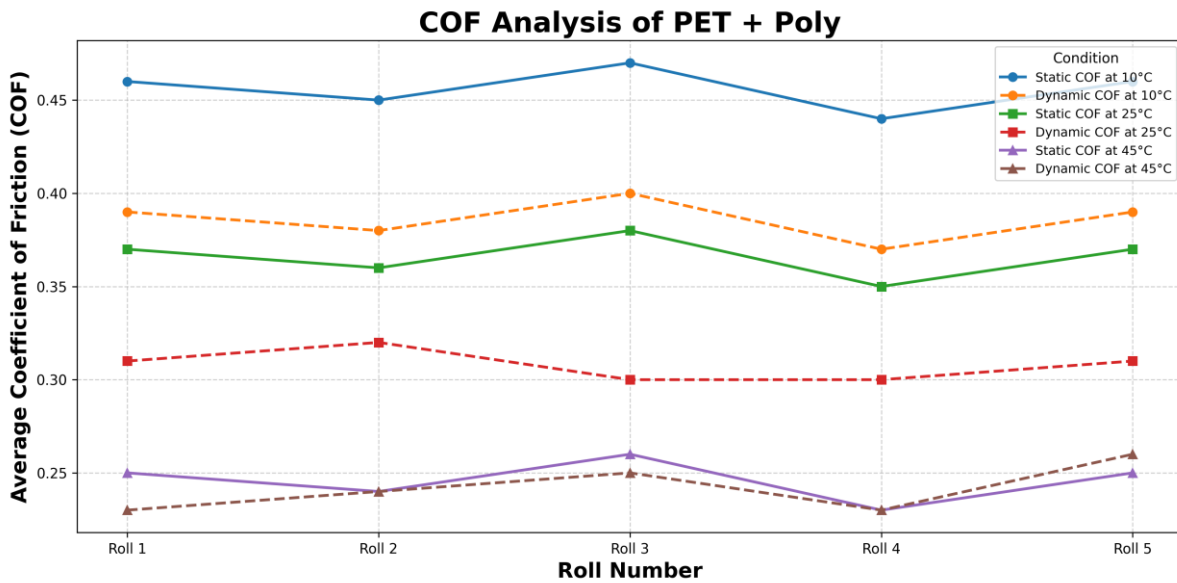


Fig.3.

COF Analysis of PET + Poly

The fig.3. indicates that static COF values were consistently higher than dynamic COF values across all testing conditions. At 10°C, the laminate showed the highest static and dynamic COF values compared to other temperatures, suggesting increased surface friction due to reduced flexibility and greater surface rigidity at lower temperatures.

At 25°C, both static and dynamic COF values slightly decreased. The laminate surface exhibited smoother slip behavior and stable frictional properties under typical environmental conditions. This reduction in COF values reflects improved surface movement and enhanced machinability during packaging operations.

At 45°C, most roll samples displayed the lowest COF values. The elevated temperature softened the Poly layer, reducing surface resistance during sliding. Consequently, smoother surface interactions and lower frictional resistance were achieved.

Across all roll samples, only minor variations in COF values were observed, likely due to differences in surface treatment, coating uniformity, or manufacturing process conditions. Nevertheless, the overall COF performance of the PET + Poly laminate remained consistent throughout the testing conditions.

Overall, the PET + Poly laminate demonstrated satisfactory static and dynamic COF characteristics across all conditioning temperatures, indicating good slip behavior and reliable surface properties suitable for flexible packaging applications.

6.2.4 WVTR

The WVTR test was conducted to evaluate the moisture barrier properties of the PET + Poly laminate at various conditioning temperatures. This test provides insight into the amount of water vapor that can permeate the laminate under different environmental conditions. Lower WVTR values signify better moisture resistance and enhanced protection for packaged products.

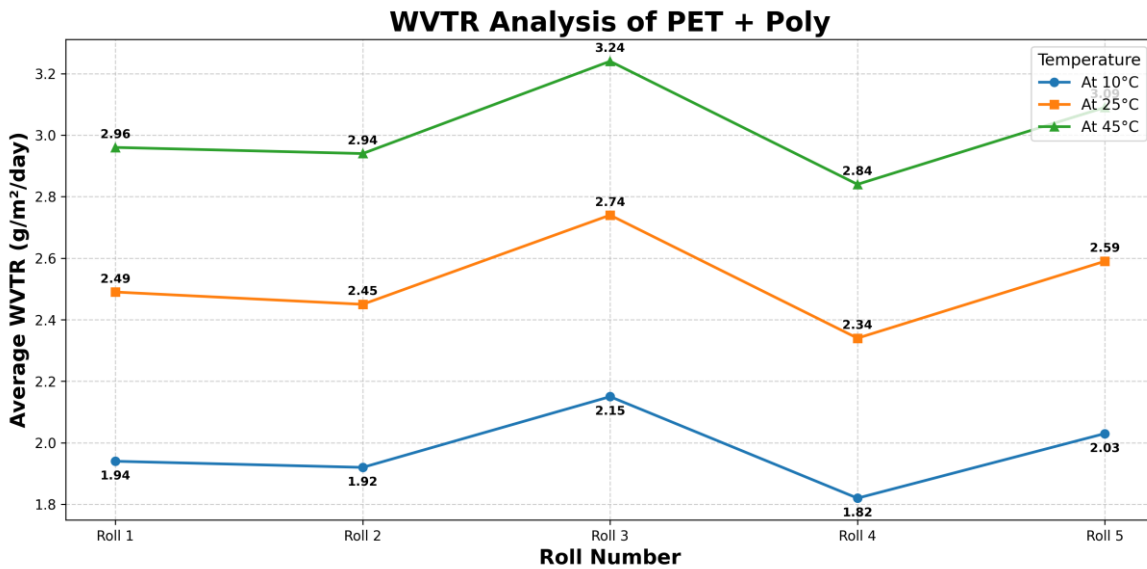


Fig.4. WVTR Analysis of PET + Poly

The above fig.4. it can be observed that the WVTR values increased gradually with increase in temperature. At 10°C, the laminate showed lower WVTR values for all roll samples, indicating better resistance against moisture transmission. Reduced molecular movement at low temperature restricted the passage of water vapour through the laminate structure.

At 25°C, moderate WVTR values were obtained. The laminate maintained stable moisture barrier properties under normal room temperature conditions. Roll 3 showed comparatively higher WVTR values, while Roll 4 exhibited lower moisture transmission among all samples.

At 45°C, the highest WVTR values were recorded for most roll samples. Increase in temperature enhanced the permeability of the polymer layers, allowing more water vapour molecules to pass through the laminate. Due to this, moisture barrier efficiency slightly decreased at higher temperature conditions.

The PET + Poly laminate exhibited acceptable moisture barrier characteristics under all testing conditions. The results indicate that the laminate can provide suitable protection for packaging applications where moderate moisture barrier performance is required.

6.2.5 OTR

The OTR test was conducted to assess the oxygen barrier properties of the PET + Poly laminate at conditioning temperatures of 10°C, 25°C and 45°C. The oxygen transmission rate is a critical factor in flexible packaging, as it influences product freshness, oxidation stability, flavor retention and the shelf life of packaged goods.

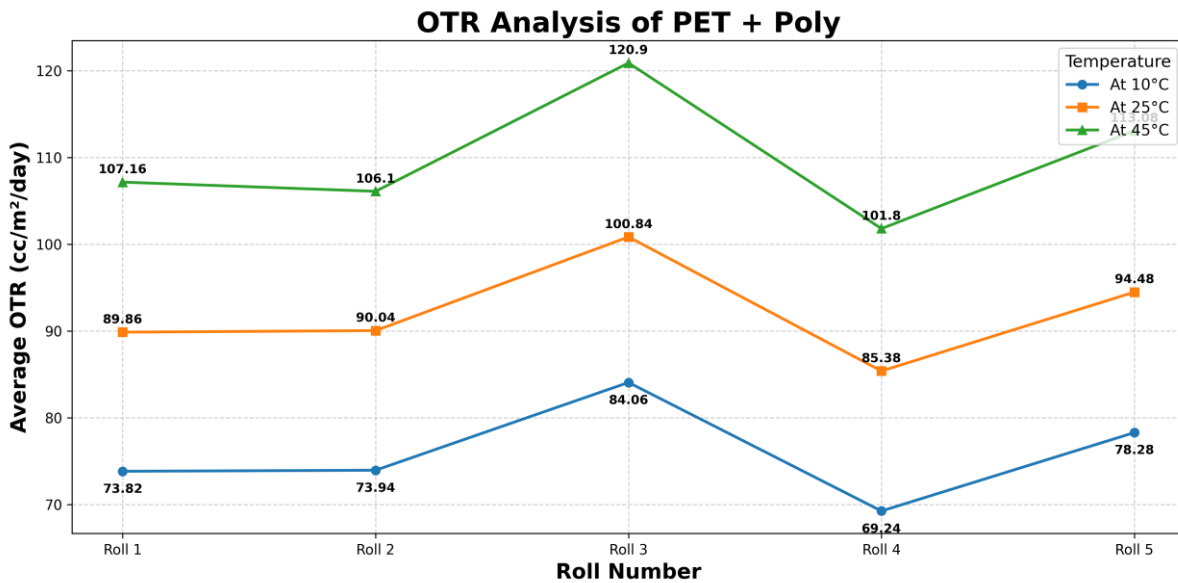


Fig.5. OTR Analysis of PET + Poly

From the fig.5. a clear increase in OTR values was observed with increase in conditioning temperature. At 10°C, the average OTR values ranged from 69.24 to 84.06 cc/m²/day. Roll 4 showed the minimum OTR value of 69.24 cc/m²/day, while Roll 3 exhibited the maximum value of 84.06 cc/m²/day. The lower OTR values at this temperature indicate comparatively better oxygen barrier performance due to reduced molecular movement within the polymer structure.

At 25°C, the OTR values increased significantly and ranged between 85.38 and 100.84 cc/m²/day. Roll 3 again showed the highest oxygen transmission value of 100.84 cc/m²/day, whereas Roll 4 maintained the lowest value of 85.38 cc/m²/day. The increase in temperature enhanced oxygen permeability through the laminate structure, resulting in higher transmission rates.

At 45°C, the highest OTR values were recorded for all roll samples. The values ranged from 101.80 to 120.90 cc/m²/day. Roll 3 showed the maximum OTR value of 120.90 cc/m²/day, while Roll 4 exhibited the lowest value of 101.80 cc/m²/day. The significant increase in oxygen transmission at elevated temperature indicates increased molecular mobility and higher diffusion rate of oxygen molecules through the PET + Poly laminate.

The results clearly show that temperature had a direct influence on oxygen barrier performance. As conditioning temperature increased from 10°C to 45°C, the OTR values increased continuously for all roll samples. This behavior indicates reduction in oxygen barrier efficiency at higher temperature conditions.

Overall, the PET + Poly laminate demonstrated stable oxygen transmission behavior with predictable variation under different environmental conditions. The laminate is suitable for packaging applications requiring moderate oxygen barrier performance and reliable packaging stability.

4. Conclusion

The evaluation of the study of PET + Poly multi-layer flexible packaging laminates and conducted tests of their mechanical and barrier properties at 10°C, 25°C and 45°C. The tests yielded an average sealing strength of 19.58N/15mm and an interlayer adhesion strength of 4.03N/15mm, confirming that the material has good packaging integrity and structural stability.

In this study, the material's static and dynamic friction coefficients were measured at 0.37 and 0.25 respectively, its water vapor transmission rate was recorded at 3.01 g/m²/day, its oxygen transmission rates at 10°C and 45°C were 75.87 cc/m²/day and 109.81 cc/m²/day in sequence, and its oxygen barrier efficiency decreased as temperature rose.

The PET + Poly composite laminate developed in this study has excellent mechanical properties and up-to-standard barrier performance and is suitable for flexible packaging scenarios that require reliable sealing, good adhesion and moderate protection against water vapor and oxygen.

The evaluation of PET + Poly multi-layer flexible packaging composite films under the influence of temperature and found that temperature exerts significant impacts on both the mechanical and barrier

properties of the composite film. Measured data from this study show that at 25°C, the film has a sealing strength of 19.58 N/15mm, an adhesive strength of 4.03 N/15mm and static/dynamic coefficients of friction (COF) of 0.37/0.25 respectively. For barrier performance, the oxygen transmission rates (OTR) recorded at 10°C, 25°C and 45°C are 75.87 cc/m²/day, 92.12 cc/m²/day and 109.81 cc/m²/day in sequence, while the water vapor transmission rate (WVTR) at 25°C is 3.01 g/m²/day. High temperatures increase the molecular mobility of the polymer matrix, which in turn leads to reduced barrier performance. A comprehensive assessment confirms that this composite film is suitable for flexible packaging scenarios that require reliable sealing and moderate oxygen and moisture barrier properties under conventional storage conditions.

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