From Surface Energy to Delamination: A multi-faceted mechanical approach for predicting Failure in EB-Printed Corona Treated PET - PE Laminates in flexible packaging

Carolina Suárez Vallejo [1,2]. Edgar Dörsam[2], Hans Martin Sauer[2]

Abstract

The flexible packaging industry is experiencing significant growth, driven by consumer demand for lightweight, convenient, and resource-efficient products. This expansion needs a parallel increase in the supply of high-performance inks and materials, particularly for multilayer laminated structures. The lamination of these structures is a complex process often compromised by issues related to adhesion, optical defects, and the long-term integrity of barrier properties. These laminates are primarily based on substrates such as Bioriented Polypropylene (BOPP) and Polyethylene Terephthalate (PET). A key technological advancement in this sector is Electron Beam (EB) curing, which offers a sustainable and efficient method for flexible packaging processing.

However, the integrity and performance of these multilayer laminates critically depend on the lamination bond strength. Despite its crucial importance, the industrial evaluation of adhesion is often limited to simple lamination force measurements and qualitative tape-peel tests. These methods are insufficient for a comprehensive characterization of the delamination process and for accurately predicting the effects of material properties or processing conditions.

This research aims to develop a robust methodology for understanding the fundamental phenomena governing the delamination of flexible polymeric materials, specifically those laminated with EB-cured offset inks. The study seeks to move beyond simple force measurements and establish a scientific framework

[1]Sun Chemical Group GmbH, Eurolab, Karlstein am Main, Germany
[2] Institut für Druckmaschinen und Druckverfahren, Technische Universität Darmstadt, Germany

that allows for the quantitative interpretation and prediction of delamination behavior.

Introduction

The cornerstone of successful lamination is robust interfacial adhesion. Flexible polymeric films possess low surface energy, which inherently hinders the wetting and bonding capabilities of solvent-free adhesives. The primary substrates under investigation are chemically or Corona-treated PET (polyethylene terephthalate) films and Corona-treated BOPP (bi-oriented polypropylene) films, all printed with Electro Bean (EB) -cured offset inks. The secondary substrate in all cases is a Corona-treated PE (polyethylene) film.

This investigation is guided to elucidate the following fundamental, practical questions: (i) How can the lamination forces of the composite structures subject to this research be improved? (ii) How do substrate properties influence the delamination mechanism in these multilayer systems? and (iii) Is it possible to establish a quantitative relationship between the qualitative tape-peel test and the measured lamination bond strength?

This research employs a multi-faceted approach that combines experimental testing with state-of-the-art physical modeling.

The T-Peel delamination test, conducted via an automated tensile tester, will be the primary method for quantifying lamination force.

These experimental findings will be integrated with advanced theories of adhesion and delamination (including those proposed by de Gennes [1] [2], Kaelble [3], and Bikerman [4] [5] [6], among others) to deepen the understanding of the parameters controlling the delamination process in this specific application. This research is expected to establish a clear and quantifiable relationship between the surface properties of the primary and secondary substrates and the resulting lamination bond strength. By creating a scientific basis for interpreting delamination behavior, this work will enable a more informed decision-making methodology in the design of flexible polymeric structures.

The findings will provide a quantitative framework for performance prediction, moving the industry beyond qualitative assessment methods. Ultimately, this will contribute to the development of more durable and reliable flexible packaging solutions, directly benefiting packaging technology developers and manufacturers.

Electron Beam (EB) printing technology

Electron beam curing uses the high energy of accelerated electrons to directly cause the cross-linking of inks and coatings.

In this case: The high energy of this curing process ensures that a high degree of conversion from oligomer to polymer takes place [7] [8] [9] [10].

Lamination in the flexible packaging industry

In many cases, the lamination interface is not visually discernible, particularly when the substrates exhibit high optical transparency or when the multilayer structure shows minimal contrast between layers. This is typical in configurations where a transparent film is laminated onto another transparent substrate, resulting in no observable change in refractive index at the interface, such as in structures with a metallized inner layer and printed graphics on the outside.

A typical lamination structure consists of a primary film (such as corona-treated PET, chemically treated PET, or corona-treated BOPP) followed by the EB offset ink layer. Then, it is laminated using a solvent-free adhesive system based on isocyanate and hydroxyl chemistry. The final layer is the secondary film, which is corona-treated PE along this research.

De-lamination is the separation of the laminate layers. Through the de-lamination it is possible to define the Laminate Bond Strength (LBS) as a mechanical property to define how strong the lamination is [11] [12].

The Problem of Lamination Bond Strength

Delamination tests are usually carried out using T-peel test equipment, considering the determination of the maximum force used in the process as a parameter indicative of the goodness of the lamination (LBS) [13]. This force is determined by means of load curves (force vs. propagation extension). The propagation extension corresponds to the length of the specimen portion that delaminates during the test Figure 1, illustrates typical load curve behaviors. The presented curves are schematic and, although they correspond to actual tests, their intent is not to present, for now, a quantitative but rather a qualitative behavior of the delamination tests. Indeed, Figure 1(a) presents the behavior such that the existence of similar loads for two different specimens does not necessarily mean that the laminate is of equal quality.

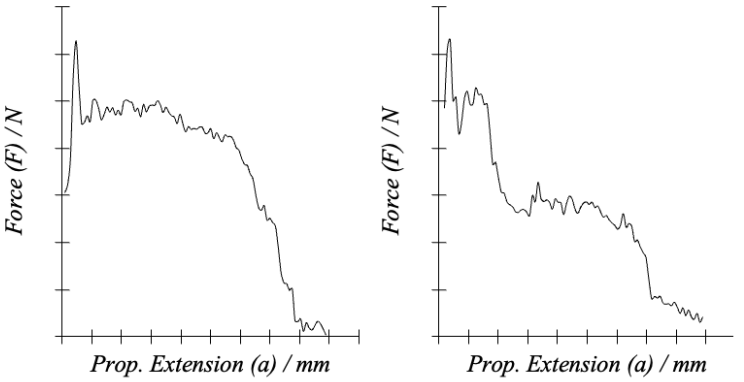


Figure 1a: Load curve showing different delamination with similar maximum loads

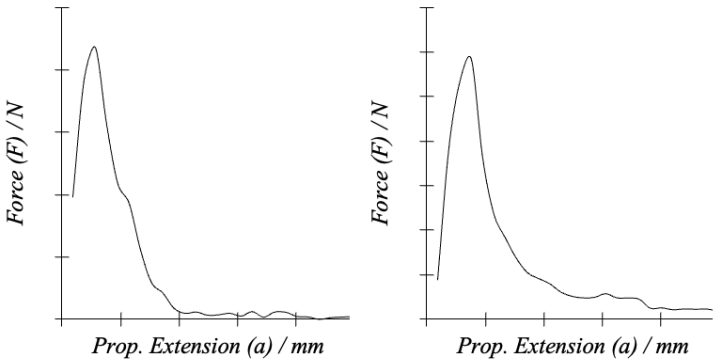


Figure 1b: Load curves showing similar delamination with similar maximum loads

In other cases, such as the shown in Figure 1 (b), different samples present a slight variation in the maximum loads. Once again, this parameter is insufficient to describe the behavior of the adhesion. It may also happen that the load curve does not present an absolute maximum, therefore, although the LBS criterion could be applied, the question remains about its benefit in terms of being an unequivocal descriptor of the delamination behavior, as shown in Figure 1(c).

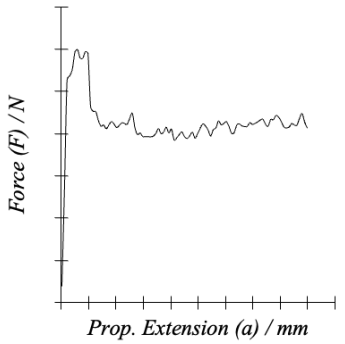


Figure 1c: Load curve showing delamination test with multiple local load maxima

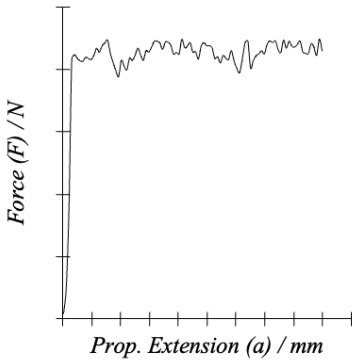


Figure 1d: Delamination test without a well-defined maximum load

Subsequently, there may be many varied cases in which the maximum load obtained in the test is not sufficient to describe the behavior of the specimen during the delamination process. Finally, the case may arise whereby delamination occurs at a practically constant and monotonic load, as shown in Figure 1(d).

The Work of Adhesion

The work of adhesion (W_a) is defined as the specific work done by the Auto Tensile Tester on the specimen to delaminate it [14]. It is considered a parameter by means of which a first comparison of the response of the specimens to the delamination process can be made. Then, the work of adhesion between two surfaces W_a,can be calculated by means of equation (1). Where A is the effective area of delaminated specimen, F is the force applied during the delamination test and a is the propagation extension, meaning the length of the delaminated front

that is propagated during the test. In other terms, the work of adhesion is the "area under the curve" of the load curve obtained during the delamination test [3].

$$W_a = \frac{1}{A}\int F\,da \tag{1}$$

The work done by the Auto Tensile Tester and its effect on the delamination of the specimen can be described from the structural mechanics as a Double Cantilever Beam configuration [15]. The Figure 1 shows a scheme of this configuration, where the specimen is loaded by pulling apart the two beams (films) at a certain rate, thus increasing load P (or force F) resulting in increased extension δ of two beams and generate a crack with length a (propagation extension). It directly depends on geometry, the force (load) and in general, on the elastic and plastic properties of the materials (substrates, ink, adhesive).

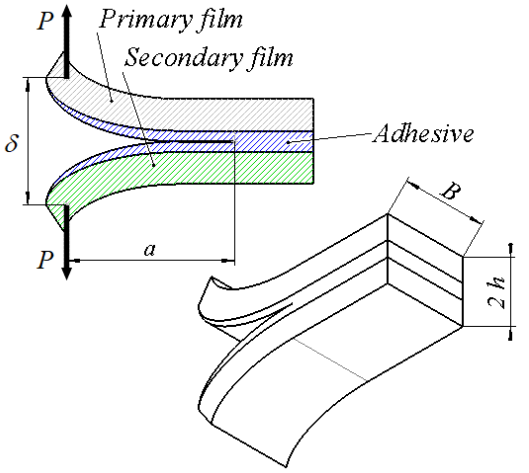


Figure 2 Schematic double cantilever beam configuration. (Based on [16])

Ratio between force amplitude and the average force in load curve plateau

In the load curve, the plateau corresponds to the region in which the least variation of force can be considered, that is, the range in the propagation extension of the T-Peel Test in which stability is observed [16].

In that stable region, the force amplitude (A_{PV}) captures macroscopic adhesive events: fracture events (where the force increases) and rearrangement events (where the force decreases), during which a residual force remains as the crack front moves from one anchoring point to the next [16].

In this sense, the relationship between the force amplitude and the maximum force allows establishing a quantitative parameter to define at what level the adhesive suffers these fracture and repair events, and therefore, gives an idea about the efficiency of the adhesive [16].

Compliance

Compliance describes how the laminated structure responds to applied stress, indicating whether the material behaves predominantly elastically or displays a more rigid response. A gradual increase in compliance with extension suggests uniform energy absorption within the system, promoting stable delamination and minimizing the risk of substrate rupture. In contrast, an abrupt change in the slope of the compliance with extension indicates that the applied force has exceeded the elastic limit of the film, initiating the onset of tearing. [15].

Compliance can be calculated directly from the data provided by the Auto Tensile Tester according to equation (2). Where δ is the extension and F is the force applied during the delamination test. Since both the extension and the applied force are variable during a delamination test, the compliance of the specimen is expected to vary during the test. [15].

$$C = \frac{\delta}{F} \tag{2}$$

The slope, or derivative, of compliance respect to propagation extension, according to equation (3), represents the combined stiffness of the adhesive and the substrates. Birkeman explains that for laminates made with flexible polymeric films, the relation between the compliance and the propagation extension during a delamination process should obey a linear behavior, it means that the slope of the curve must be a constant. [15] [16].

$$\frac{dC}{da} = m \tag{3}$$

Strain Energy Release Rate

The strain energy release rate (G) is a well-established parameter used in the description of fracture mechanics [3]. It is a measure of the adhesive's toughness or its resistance to fracture within a given laminate system. Consequently, it depends not only on the adhesive itself but also on the properties of the films that constitute the laminate.

The equation (4) allows to determinate the strain energy release rate direct from the delamination test with the Auto Tensile Tester. Since from this definition, the

strain energy release rate in independent of the elastic or plastic properties of the film, this is the called its "ideal" form, where b is the weight of the laminated specimen [3].

$$G = \frac{2 \cdot F}{b} \tag{4}$$

Equation (5) describes a better definition of the strain energy release rate. According to this equation, the real form accounts for the effects of the elastic or plastic behavior of the films during the delamination through the derivative of compliance (C) respect to the propagation extension (a), it is the way in which the delamination fracture is propagate in the specimen during the delamination test [3].

$$G = \frac{F^2}{2 \cdot b} \cdot \frac{dC}{da} \tag{5}$$

Equations (4) and (5) state that the energy release rate is variable during the delamination test. For this reason, it is necessary to define a value that allows the laminated specimen to be characterized. The critical energy release rate (G_C) corresponds to the average value obtained during the peel test and can be used as an overall indicator of the adhesive's integrity under stress. Above this threshold, the adhesive has already failed; at stress equal to or below this level, crack propagation will occur in a stable manner, typically without rupturing the films. Any applied force that produces an energy release rate exceeding the critical value will result in adhesive fracture or peel [4].

The narrower the range of the energy release rate, the more efficiently the adhesive performs within that laminate system [4].

According to the equation (6), the ratio between the maximum energy release rate (G_{max}) observed during the delamination test and the critical energy release rate (G_C) indicates the brittleness (b_i) of the adhesive. This property reflects the ability of laminate to dissipate energy before fracturing and, therefore, its effective elasticity [5].

$$bi = \frac{G_{max}}{G_C} \tag{6}$$

Adhesive spring constant

By means of a delamination test such as the T-Peel, Kaelble [3] proposes the possibility of defining the adhesive spring constant (k). It reflects the ability of the adhesive to interact effectively with substrates subjected to different levels of force. That is, It represents the rigidity of the adhesive bond and its ability to resist

deformation under load. It is defined according to equation (7). Where $(E \cdot I)_{eq}$ represents the flexural rigidity of a beam, $C_{interfase}$ is the compliance of the interface adhesive-film [3].

$$k = \frac{4 \cdot (E \cdot I)_{eq}}{b} \cdot \left[C_{interfase} \cdot b \cdot (E \cdot I)_{eq}\right]^{-4/3} \quad (7)$$

The flexural rigidity $(E \cdot I)_{eq}$ is defined according to equation (8). Where E is the Young's modulus of elasticity; which measures the stiffness of the material, I is the moment of inertia; which measures the geometric stiffness based on the cross-sectional shape. PF and SF refers to primary and secondary films respectively [3].

$$\frac{1}{(E \cdot I)_{eq}} = \frac{1}{(E \cdot I)_{PF}} + \frac{1}{(E \cdot I)_{SF}} \quad (8)$$

The compliance of the interface adhesive-film $C_{interfase}$ is defined according to equation (9). Where C_{arms} is the compliance only due to the movement and plastic or elastic behavior of the films [3].

$$C_{interfase} = C - C_{arms} \quad (9)$$

The compliance C_{arms} is defined according to equation (10) [3].

$$C_{arms} = \frac{a}{b} \cdot \left[\frac{1}{(h \cdot E)_{PF}} + \frac{1}{(h \cdot E)_{SF}}\right] \quad (10)$$

Materials and methods

For all experiments, commercial substrates like BOOPP, Corona treated PET and chemically treated PET (PET-Chem) as printing substrates (primary films) and Corona treated PE as secondary film for lamination applications, were used. Table 1 shows the properties of the substrates and their supplier.

Corona treatment is applied on BOPP, PET, and PE films by a laboratory scale equipment (Ahlbrand corona system generator type FG3101-LCD, Baldwin Technology GmbH, Germany). The primary substrates (BOPP and PET) were irradiated at 300 W and the secondary (PE) at 600 W (Power Supply Output, PSO). The electrode passing speed over the substrate (line speed, LS) was 11,7 m min-1, it occurs in one (1) pass Ps. The electrode width E_W was 0,30 m. The equation (11) allows to calculate the irradiation dosage on the surface, parameter known as "watt density W_d".

Properties	Symbol	Unit	PET	BOPP	PE
Density	ρ	kg m^{-3}	1380 – 1560	905	939 – 960
Glass transition temperature	T_g	°C	67 – 80	– 20	– 110
Shear modulus	G	MPa	525 - 2432	680 – 920	750
Tensile strength	σ	MPa	40 – 60	25 – 33	26
Thickness		µm	12	20	60
Young's modulus	E	MPa	1000 – 3500	2500 – 4500	620 – 860
Supplier			Transparent Paper Ltd/ Polyplex	Taghleef Industries	Südpack

Table 1. Main physical properties of polymers used in this research. [17] [18] [19] [20] [21]

$$W_d = \frac{PSO}{E_W \cdot LS \cdot Ps} \tag{11}$$

The inks used for curing via electron-beam irradiation comprise unsaturated monomers (with double bonds), oligomers, and various additives, depending on the required properties. The unsaturated oligomeric components in electron beam-curable inks primarily include oligoesters and their acrylates, polyether and polyurethane acrylates and epoxy acrylate resins. Reactive oligomers with unsaturated double bonds in their short molecular chains play a crucial role in radiation-induced crosslinking, as well as in coating and composite processing [22]. Substances such as trifunctional or tetrafunctional acrylate monomers and oligomers are usually included. For pigment dispersions, it is common to use urethane, aldehyde, or aliphatic resins. In many cases, the use of special dispersant and stabilizer additives is necessary to keep the properties of the formulation. The measurement of viscosity and tack were taken as quality properties from which the inks were considered suitable for printing. The expected viscosity for the used inks was adjusted to values suitable for EB offset printing. To measure this property, the plate-plate geometry of a rheometer (Anton Paar GmbH, Type MCR 102, Austria) was used, and the property was measured at 23,0 °C. The tack should fit the typical values of EB offset printing as well. To measure this property, a Tack Analyzer (LithoTack II, Novomatics GmbH, Germany) was used. The tack was determined at 30 °C and a rotation speed of 800 rpm.

The printing was performed under industrially relevant velocity, dose and voltage conditions on a wide-web offset press. Up to 800 m of the polymeric substrates that are the subject of this investigation were printed. This printing process applied uniform pressure at each color station, which results in better tension control for substrates and prints. On this machine the decks are arranged around a single impression cylinder.

Samples printed at an industrial scale were used for lamination of specimens at a semi-industrial scale (laminations made with an automatic laminator, the Labo Combi 400 type laminator (Nordmecanica SPA, Italy). Four commercially available solvent-free polyurethane adhesives, with different viscosities, reactivities and composition of hardeners were evaluated.

The adhesives were applied at an average temperature of 47,1 °C (± 10,6 %). The amount of adhesive corresponds to a load of 2,0 g m-2 (± 4,85 %), that was applied at a speed of 60,0 min-1, at a pressure of 3,0 bar, and with a film tension of 25,0 N. Then, to finish the adhesive curing, the laminated is placed in an oven (Temperature Applied Sciences Ltd, MTCL 135, England) between 5 and 7 days at 21,0 °C.

An Auto Tensile Tester (LRX, Llyod Instruments, UK) was used to delaminate specimens manufactured on a semi-industrial scale. Laminates with fixed dimensions (15,0 mm × 21,0 cm) were delaminated at a speed (T-peel) of 100 mm min-1, supported at a peel angle of 90,0°.

Results and Discussion

Figure 3 shows the Lamination Bond Strength (LBS) during the delamination of laminates made with different primary films; all printed with cyan EB ink, different adhesives and corona-treated PE as secondary film. The value of the columns represents the average LBS and the error indicator considers the maximum and minimum value. Those values have been obtained from three different samples of the same laminate subjected to the delamination test.

From the information presented in Figure 3, Adhesive 1 is mostly which shows the lower performance based on LBS.

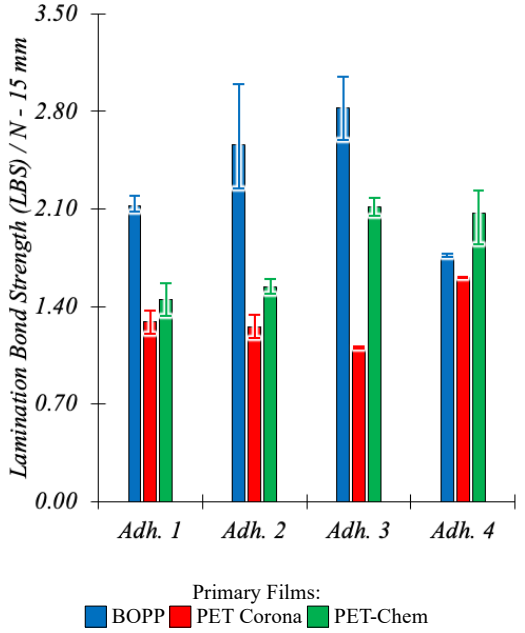


Figure 3 Lamination bond strength for laminates made with primary films printed with cyan ink and PE as the secondary film.

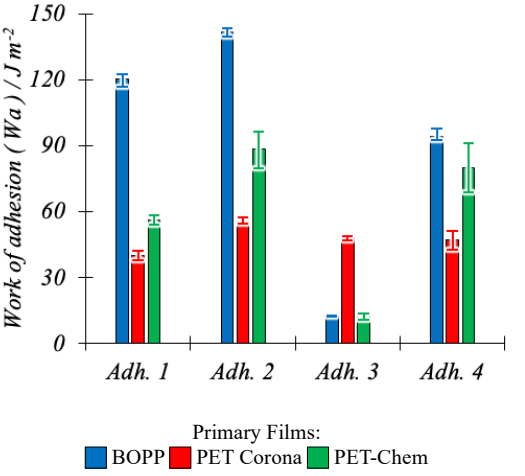


Figure 4 Work of adhesion for laminates made with primary films printed with cyan ink and as secondary film.

Figure 4 shows the work of adhesion during the delamination of laminates made with different primary films; all printed with cyan EB ink, different adhesives and corona-treated PE as secondary film. The value of the columns represents the average work of adhesion, and the error indicator considers the maximum and minimum value. Those values have been obtained, through equation (1), from three different samples of the same laminate subjected to the delamination test.

Figure 4 shows the work of adhesion, which helps compare laminates even when their force curves differ. It reflects not only the energy needed to delaminate, but also how the force is applied and dissipated in the materials. For this trial, the test on BOPP film in combination with Adhesive 2 shows the highest work of adhesion. The values obtained with Adhesive 3 are significantly lower for both BOPP and chemically treated PET. At this point, by comparison Figure 3 and Figure 4, it is possible to see that the LBS (Lamination Strength) is not a sufficient parameter to describe the advantages of one laminated specimen compared to another. Indeed, although the tests performed on the specimens formed with Adhesive 3 showed lamination forces comparable to those of the other adhesives, the bond strengths associated with this adhesive were low. In these cases, the laminated specimens began delaminating at a high force value, and then the process continued with significantly lower mechanical strength than that offered by the other adhesives.

Figure 5 shows the ratio between the Amplitude between peaks and valleys (A_{PV}) and the average force in the plateau test (F_{avg}) during the delamination of laminates made with different primary films; all printed with cyan EB ink, different adhesives and corona-treated PE as secondary film. The value of the columns represents the average value.

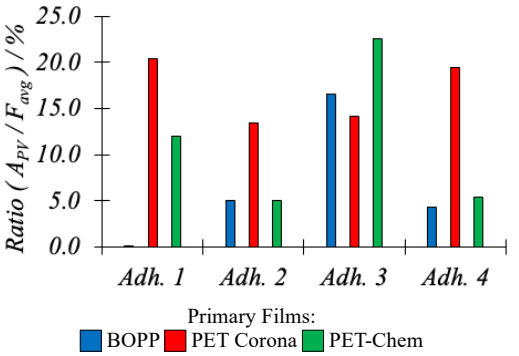


Figure 5 Ratio between force amplitude and the average force for laminates made with primary films printed with cyan ink and PE as secondary film.

Figure 5 provides an overview of the adhesives, showing that Adhesive 3 exhibits the least affinity for the different substrates, as its ratio values are the highest. In contrast, Adhesives 1 and 4 show good affinity, particularly for specimens with a BOPP primary film.

Similarly, based on the behavior of the primary substrates, their affinity with the adhesives is such that BOPP > PET-Chem > PET Corona, as has been observed in the practical application of flexible polymer packaging. Based on the parameter of the ratio between peak and valley amplitude and the average force during delamination, it is observed that, in the case of specimens laminated with PET-Corona, there is not a good affinity between the adhesive and the substrates.

Figure 6 shows the compliance range in the plateau of the laminates made with different primary films; all printed with cyan EB ink, different adhesives and corona-treated PE as secondary film. The columns represent the compliance range, and the points represent the average values. Those values have been obtained, through equation (2), from three different samples of the same laminate subjected to the delamination test.

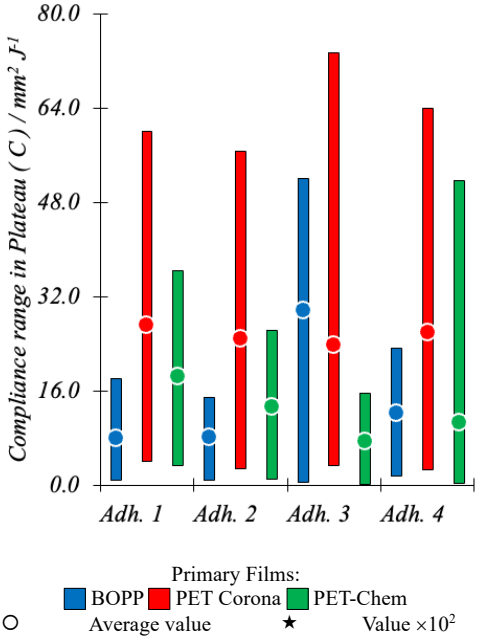


Figure 6 Compliance range for laminates made with primary films printed with cyan ink and PE as secondary film.

According to Figure 6, except for Adhesive 3, in the other adhesives the laminates made with corona-treated PET have higher average compliance values and also wider ranges of this parameter. This is an indicate that the adhesives have not formed sufficient hydrogen bonding with the substrate. Under these conditions, the adhesive behaves more like a viscous fluid that elongates under load (greater extension under applied force) but fails to establish an effective bond with the films. Whit the same point of view, in the case of printed BOPP films, very low compliance values lead to film rupture, as the adhesive fracture interface becomes excessively rigid. By contrast, for chemically treated PET, intermediate compliance values allow delamination to occur under expected load conditions, with or without substrate failure.

Figure 7 shows the range of energy release rates in the plateau during the delamination of the laminates made with different primary films; all printed with cyan EB ink, different adhesives and corona-treated PE as secondary film. The columns represent the range of energy release rate, and the points represent the average values. The dashed columns and the empty points represent the ideal behavior calculated according to equation (4). The filled columns and the filled points represent the compliance-based behavior calculated according to equation (5). All values have been obtained from three different samples of the same laminate subjected to the delamination test.

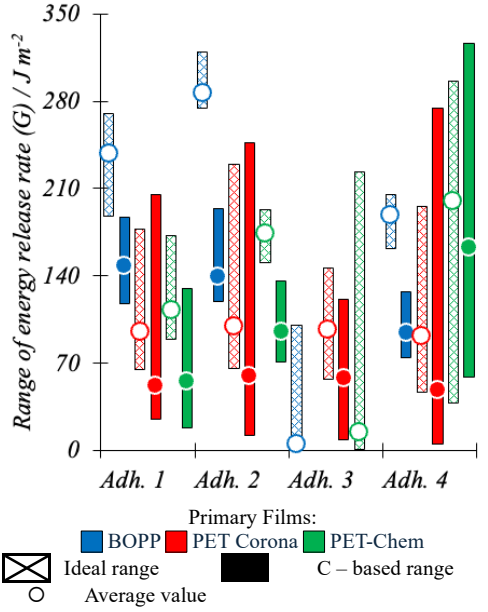


Figure 7 Range of energy release rate for laminates made with primary films printed with cyan ink and PE as secondary film.

The toughness of the adhesive within a specific laminate system increases with higher critical energy release rate values. On the other hand, when the energy release rate values vary substantially with the extension spread across different laminate systems (i.e., when the energy release rate exhibits a wide range), it indicates that the adhesive offers lower resistance to applied forces and is therefore more prone to failure. This behavior is observed, for example, with Adhesive 1, it exhibits a narrower range (and thus greater efficiency) when used with chemically treated PET compared to corona-treated PET.

Figure 8 shows the range of the derivative of compliance respect to the propagation extension in the plateau during the delamination of the laminates made with different primary films; all printed with cyan EB ink, different adhesives and corona-treated PE as secondary film.

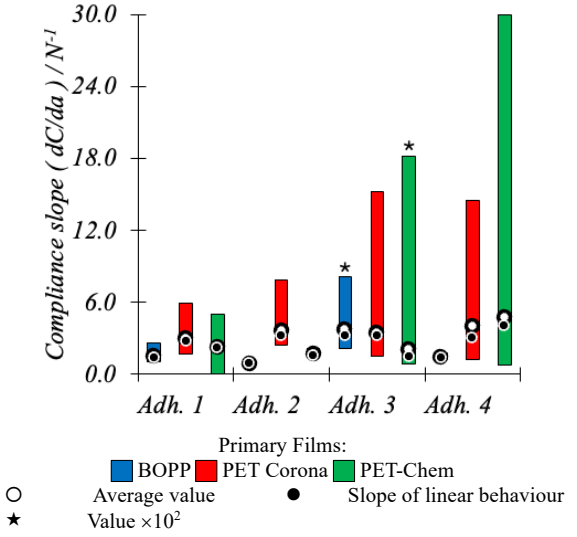


Figure 8 Derivative of compliance for laminates made with primary films printed with cyan ink and PE as secondary film.

The columns represent the range of the derivative, the empty points represent the average values for that range, and the filled points represent the slope when the relation between compliance and propagation extension is considered linear. All values have been obtained from three different samples of the same laminate subjected to the delamination test.

Since for laminates made with flexible polymerical thin films, the compliance theoretically behaves as a first-degree polynomial respect to the propagation extension, meaning that it is a linear function, the derivative is therefore equal to

the slope. The proximity between the average value of the high order derivative and the slope of linear behavior justify why the evaluated systems conform well to the theoretical models, such as models from Bikerman [4] [5] [6], expected for thin polymer films, and give a probed background to analyse the mechanical behavior of the laminates subject of this study beyond the use of Lamination Bond Strength alone.

In Figure 8, a well-bonded system, such as chemically treated PET or BOPP, exhibits a lower slope than corona-treated PET. Indicating that these laminates are less prone to deformation (i.e., changes in extension spread) in response to variations in applied force.

Figure 9 shows the range of the adhesive spring constant in the plateau during the delamination of the laminates made with different primary films; all printed with cyan EB ink, different adhesives and corona-treated PE as secondary film. The columns represent the range of k, the points represent the average values All values have been obtained from three different samples of the same laminate subjected to the delamination test.

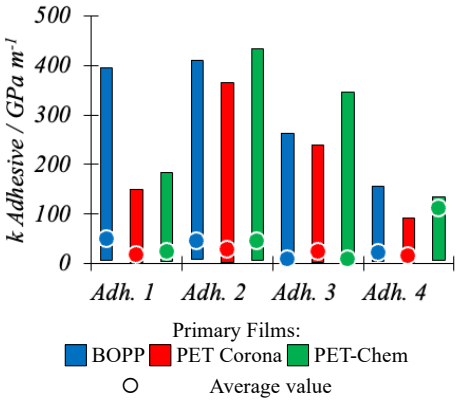


Figure 9 Range of adhesive spring constant for laminates made with primary films printed with cyan ink and PE as secondary film.

The similar average values, and same order of magnitude ranges, for several adhesives shown in Figure 9 indicate that there is no significant difference between the elastic behavior of adhesives used in this investigation. This result leads to a mayor effect of the interaction between the adhesives and the polymeric films and the film properties over the capacity of laminates to support the effect of external loads before the delamination. Nevertheless, it is possible to prove that the plastic behavior of laminate components and its effect over the delamination is not significant, it means that the adhesive-film interaction is the characteristic that controls de delamination process.

Figure 10 shows the average value of the brittleness index in the plateau during the delamination of the laminates made with different primary films; all printed with cyan EB ink, different adhesives and corona-treated PE as secondary film. All values have been obtained from three different samples of the same laminate subjected to the delamination test.

In Figure 10 a higher value of the brittleness index implies that the adhesive dissipates less energy when subjected to stress and is consequently more prone to brittle fracture. In that case Adhesive 4 in combination with all tested films presented the highest fracture trend.

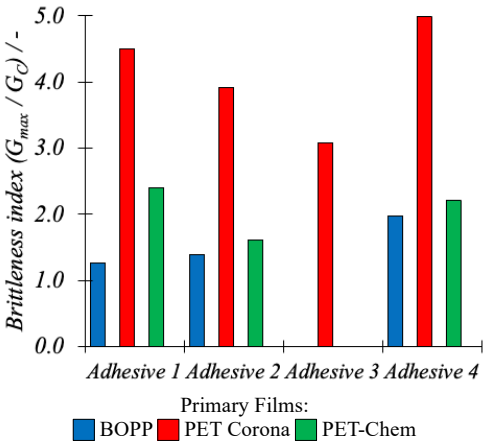


Figure 10 Brittleness index for laminates made with primary films printed with cyan ink and PE as secondary film.

According to Figure 10 it is notable that the laminates made with corona-treated PET had higher tendency to be delaminated, even five times higher than de possibility to delaminate specimens made with BOPP.

Conclusions

All experimental results are mutually comparable, as the testing conditions, measurement protocols, and analytical procedures were maintained consistently throughout the study. This methodological uniformity ensures that any differences observed among the samples arise from the intrinsic properties of the laminate systems and adhesives under evaluation, rather than from variability in the experimental setup. Consequently, the comparative analysis remains robust, reliable, and scientifically meaningful.

A systematic approach to evaluate and predict the quality of laminates made of thin polymer films as a method beyond Lamination Bond Strength (LBS) was presented. It includes the effect of several parameters on the adhesion issues. Namely, work of adhesion (W_a), compliance (C),and strain energy release rate (G) are key parameters in the delamination physics and have been used to compare and interpretate the experimental results.

The relationship between those parameters and LBS is considered relevant for the evaluation of the complete lamination system included the films, adhesives and inks.

Adhesive characteristics obtained from delamination tests permit to have a huge overview of its performance in different films combinations.

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