

Market Trends, Opportunities and Latest Process Innovation in Vacuum Metallization – Introducing BOBST AluBond® Technology

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ABSTRACT

The market expectations for commodity grade metallized film continue to increase in complexity based on the global market trends. Cost pressures are driving substrate down gauging, packaging structure simplification/ reduction, greater use of more heat-sensitive substrates, higher barrier functionality and higher adhesion requirements. This paper will focus on a new innovative vacuum based hybrid coating technology named AluBond®, which greatly increases the adhesion level obtained on the produced metallized film whilst also improving the barrier functionality to levels which provide significant market interest.

1 INTRODUCTION

In the extremely cost-sensitive market for flexible food packaging, the quest for higher performance packaging materials on one side and the ongoing requirement of cost reduction on the other side continue to present new challenges to platform providers of vacuum metallizers and other conversion equipment as well as the converting industry itself. Hereby, substrate down-gauging, layer reduction (going from triplex to duplex laminate structures and mono-web materials), wide web metallization and metallization of more heat-sensitive polyolefin based substrates play an important role as key market drivers. These market trends demand vacuum metallizer platforms with improved process performance (e.g. regarding barrier and adhesion characteristics, but also in terms of temperature/heat load management for thin-gauged and heat-sensitive substrates), increased output and better productivity that can reliably, consistently and simply produce material of consistent and good quality at a reduced production cost.

In regards to enhanced process performance, high barrier metallization for foil replacement and increased shelf life, higher surface energy and better surface energy retention of the vacuum deposited layer as well as high metal adhesion/bond strength are critical requirements. Whilst in the past, lower metal adhesion levels appeared to be sufficient and acceptable, the industry is now frequently asking for metal adhesion greater than 2 N/(15 mm), sometimes even up to 6 or 7 N/(15 mm), although, most adhesives typically fail around 2 to 3 N/(15 mm) in laminate structures. This is due to the fact, that although the 'single layer' metal adhesion, frequently measured via seal/peel tests with ethylene acrylic acid (EAA) film [1, 2], appears sufficient, failure/delamination in the laminate structure can take place at the metal-polymer interface at a lower bond strength value than obtained in the EAA peel test. Thereby, the type of laminate structure (duplex/triplex), adhesive as well as the sealant web type and thickness are important and will impact the failure behavior.

The requirement of higher metal bond strength in aluminum metallized films is currently being addressed in various ways, using for example special chemically coated/treated film substrates, additional offline pre-treatments in atmosphere such as atmospheric pressure glow discharge treatment or flame treatment and, finally, high power plasma pre-treatment or

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multiple plasma pre-treaters inside the vacuum metallizer. Nevertheless, the use of chemically coated/treated substrates typically entails additional costs due production/processability implications for the film producer (line speed reduction) and, furthermore, can potentially be detrimental to barrier properties once combined with vacuum coating technology. The effect of offline treatments on the other hand can significantly reduce over time, hence decreasing the positive impact on metal adhesion, and also issues with treatment consistency and uniformity have been reported. In addition to that, flame treatment can induce thermal implications for heat-sensitive and down-gauged substrates.

BOBST AluBond® technology, however, is a novel, unique and elegant approach to vacuum metallizing that can achieve outstanding metal adhesion beyond the levels accomplished using conventional inline plasma pre-treatment and without the need for any additional inline or offline treatment. The technology involves the deposition of a hybrid coating layer, which has a tailored coating stoichiometry & gradient that exhibits vastly enhanced anchoring properties to the base polymer substrate. Thus, adhesion levels comparable to those obtained on chemically coated/treated films can be achieved, without the additional cost and complexity of the latter and, more importantly, without impairing the barrier performance of the metallized product. In fact, results are showing a rather positive impact on barrier performance, especially noticeable for cast polypropylene (CPP) and biaxially oriented polypropylene (BOPP) substrates when metallized using AluBond® technology. In addition to the benefits of adhesion and barrier enhancement, AluBond® metallized films can also offer higher surface energy levels of the metallization layer and better retention of surface energy (dyne) level with time when compared to standard metallized films. This paper will therefore present and discuss our latest results in terms of adhesion levels on various substrates, assessed via a range of peel test methods, dyne level retention and barrier performance for AluBond® metallized polymer films.

2 EXPERIMENTAL

2.1 METALLIZING PROCESS AND PLATFORMS

A variety of standard packaging/metallizing grade polymer films (polyethylene terephthalate (PET), CPP and BOPP), typically corona treated by the film manufacturer, were used in this assessment and were metallized using Bobst Manchester Ltd (Heywood, United Kingdom) K5 and K5 EXPERT vacuum metallizers equipped with AluBond® process technology. The metal deposition took place at speeds up to 860 m/min. Reference non-AluBond® samples for each trial have been produced using the same base film material.

For some of the AluBond® trials and also some of the reference trials, additional in-line plasma pre-treatment using a medium frequency plasma source with magnetically enhanced water cooled electrodes was applied.

2.2 ANALYTICAL AND TEST METHODS

Measurement of coating adhesion was performed according to the EMA (European Metallizers Association) test procedure for metal adhesion (seal test) [1]. Therefore, a 2 mil (50.8 µm) thick EAA film is sealed to the metallized film surface (105 °C, 4 bar, 20 s) and is subsequently peeled off using a 180° supported peel test and a peel speed of 50 mm/min.

Laminate bond strength is measured in accordance with ISO 11339 [3] (and in parts ASTM F88 [4]) using a unsupported T-peel test at a peel speed of 100 mm/min. Additionally, a 180° supported peel test at a peel rate of 50 mm/min is also conducted (i.e. peeling equivalent to the EAA peel test). A4 samples are laminated in the laboratory using a solvent-based two-component polyurethane adhesive which is applied to the metal surface using a wire wound rod. After drying, a 70 µm thick CPP sealant film is used as secondary material in order to produce a duplex laminate structure. For the triplex laminate, a printed PET film is laminated to the metallized web with the printed side facing the metallized side. The second lamination is then carried out using a 70 µm thick CPP sealant web in order to obtain the final structure (PET print/metallized PET/CPP). In all cases, laminate bond strength tests are performed after the adhesive has fully cured.

Infrared spectra for determination of the adhesion failure plane were recorded with a Thermo Scientific Nicolet 380 Fourier transform infrared (FT-IR) spectrometer using a single bounce diamond attenuated total reflectance (ATR) accessory.

Barrier properties in terms of oxygen and water vapor transmission rates (OTR/WVTR) were analyzed in accordance with ASTM F 1927 [5] and ASTM F 1249/ISO 15106-3 [6, 7] using a Mocon Oxtran 2/20 and Systech Illinois 8001 for oxygen permeation and a Mocon Permatran-W 3/33 and Systech Illinois 7001 for water vapor permeation. Test conditions are 23 °C and 50 % relative humidity (RH) for OTR measurements and 37.8 °C and a gradient of 90 % RH for WVTR measurements.

A Bresser Researcher Trino optical microscope was used to acquire images of the metallized film samples in transmitted light mode for defect evaluation.

The surface energy/dyne level was assessed using dyne pens conformal to ASTM D2578 [8] and ISO 8296 [9]. The highest dyne pen available was 60 mN/m.

3 RESULTS AND DISCUSSION

3.1 ADHESION – EAA PEEL TEST

AluBond® adhesion assessments have been carried out on a range of polymer films from different suppliers and representative results for a variety of substrates are summarized in *Table 1*, along with non-AluBond® reference data using the same base film substrate. In order to understand the force values obtained during the peel tests and interpret/use the results correctly, it is, however, essential and absolutely critical to look at the actual mode of adhesion failure. Thereby, a range of failure modes can occur, as also discussed in a more general manner in ASTM F88 [4]. In the case of the EAA peel test for the assessment of metal adhesion, a number of modes are of importance which are stated below. Along with the individual failure modes listed, there are, of course, also combinations of these possible (i.e. partial/full metal removal with EEA material elongation).

- Full metal removal; adhesion failure at metal-substrate (PET/CPP/BOPP) interface
- Full metal removal including film skin layer; cohesive failure within the polymer substrate (typically BOPP or CPP)
- Partial metal removal
- No metal removal, EAA film delamination; adhesion failure at the metal-EAA interface
- No metal removal, no peel; EAA material elongation or EAA material break

In addition to the failure modes, also the ‘raw’ force data obtained needs to be carefully examined and extracted. Frequently, when full metal removal takes place, the initial force at the start of the peel is a lot higher than the peel force measured during the actual peel. This can be due to ‘edge’ effects caused by the sealing of the EAA film or is simply caused by the fact, that the metal layer needs a higher force to initially break/fracture before the onset of peeling. Since this initial force peak is not part of the actual peeling process, it should not be used to obtain the average peel force for the sample measured.

In general, a 1 mil (25.4 μm) EAA film is used for the EAA peel test. However, it has been found in our tests that this thickness is not sufficient to assess high adhesion metallized films with AluBond®, based on the intrinsic strength of the EAA film (the limit of EAA film of this thickness has been reported to be around 3.4 N/(15 mm) [10]); hence, a 2 mil EAA film is used, which increases the upper test limit for metal adhesion to around 6 to 7 N/(15 mm), a value similar to what has been stated by other researchers conducting EAA peel tests [11]. Nevertheless, also the 2 mil EAA film has been found to be not sufficient to assess the metal adhesion in all cases, as can be seen later from the results for AluBond® metallized PET film (refer to *Table 1*). In order to assess the locus/plane of adhesion failure, FT-IR analysis is used. This is mainly needed, when full metal removal at very high peel forces is observed (typically for AluBond® metallized BOPP or CPP films), as this is frequently a sign of substrate skin layer removal along with the metallization layer.

Table 1 – AluBond® metal adhesion results on various substrates (EAA peel test)

Structure	Description	Metal adhesion N/(15 mm)	Adhesion failure mode
PET/Al 12 μm	Metal only	0.08 \pm 0.02	Full metal removal
	Plasma (low-dosage)	0.38 \pm 0.30	Full metal removal
	Plasma (low-dosage) + AluBond®	6.12 \pm 0.21	No metal removal; EEA stretch/snap/delamination
	AluBond®	6.12 \pm 0.28	No metal removal; EEA stretch/snap/delamination
BOPP/Al 50 μm	Metal only	1.01 \pm 0.23	Full metal removal
	AluBond®	5.91 \pm 0.25	EAA stretch/PP skin layer removal
BOPP/Al 20 μm	Metal only	0.52 \pm 0.14	Full metal removal
	AluBond®	4.47 \pm 0.33	Partial metal/skin layer removal
CPP/Al 25 μm	Metal only	0.89 \pm 0.22	Full metal removal
	AluBond®	3.12 \pm 0.08	EAA stretch/PP skin layer removal

When performing peel tests on standard metallized PET films, full metal removal with the locus of failure at the PET-Al interface is the classic failure mechanism. The EAA peel force values can be increased by the use of a ‘conventional’ low-dosage in-line plasma pre-treatment (see *Table 1*); however, values of several N/(15 mm) are only obtained when high power plasma pre-treatment is applied or chemically coated PET film is used as a substrate. Nevertheless, when AluBond® metallization is performed, substantial improvement in adhesion is seen, independent of plasma pre-treatment. In this case, no peeling of the aluminum layer is

possible, but it is the EAA film that delaminates and fails due to elongation or material break. The values stated for metal adhesion are an average of the force applied that could not remove the metal layer. Hence, metal adhesion is assumed to be higher.

For standard metallized BOPP, the adhesion behavior is similar to standard metallized PET, with full metal removal and failure at the BOPP-Al interface. Peel forces are higher compared to PET, but this is due to differences in the two polymers such as rigidity. When BOPP films are AluBond® metallized, the adhesion is, again, drastically increased. In the case of BOPP, however, peeling and metal layer removal (at least partially) are typically possible, frequently accompanied by the EEA film elongating due to the large peel forces required. In this case, FT-IR analysis has been conducted and the spectra are presented in *Figure 1*. It can be seen that the spectrum of the EAA film obtained from a peel test on an AluBond® BOPP sample (in red) shows peaks that can be solely attributed to PP as well as solely to EAA. Consequently, this indicates that part of the BOPP film has been peeled off along with the AluBond® metallization layer. As the failure in a multilayer structure generally initiates at the weakest point of the system [12], it can be assumed that the adhesion of the AluBond® coating to the BOPP film exceeds the measured values, which most likely represent the adhesion between the skin layer and the core layer of the BOPP film. These results are also in line with previous findings when very high peel forces were obtained for AlO_x coated BOPP films [13].

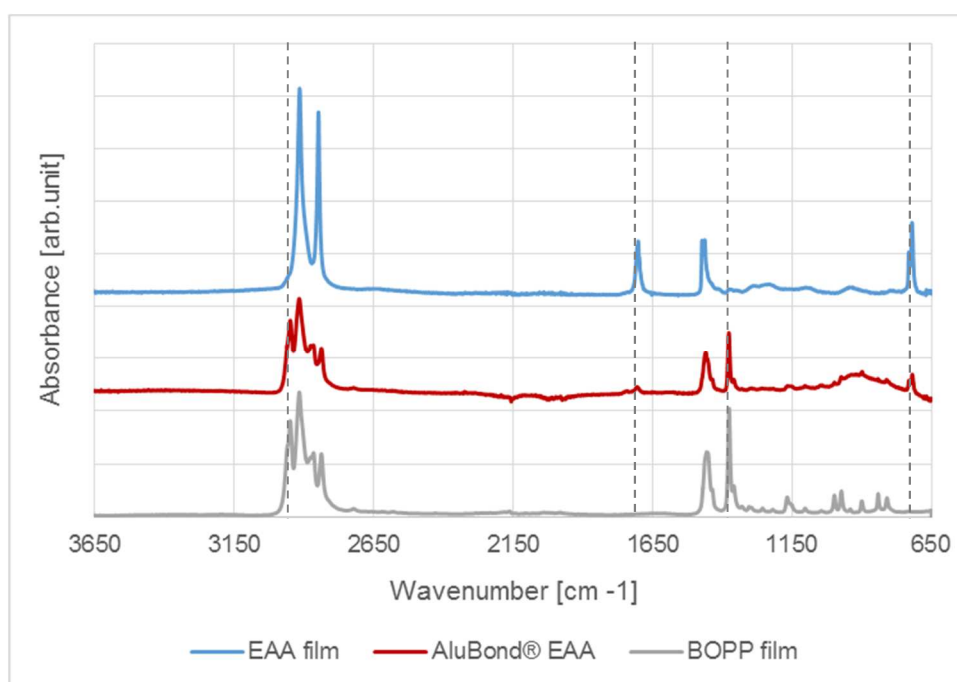


Figure 1 – FT-IR Spectra of EAA film used for peel test (top), EAA film after peel test on AluBond® BOPP sample (middle) and BOPP film (bottom)

For the standard and AluBond® metallized CPP film the results are very similar to BOPP. In both cases full metal removal was achieved, but in the case of the AluBond® film sample, part of the CPP film was peeled off along with the metallization layer (as indicated by the results of FT-IR analysis).

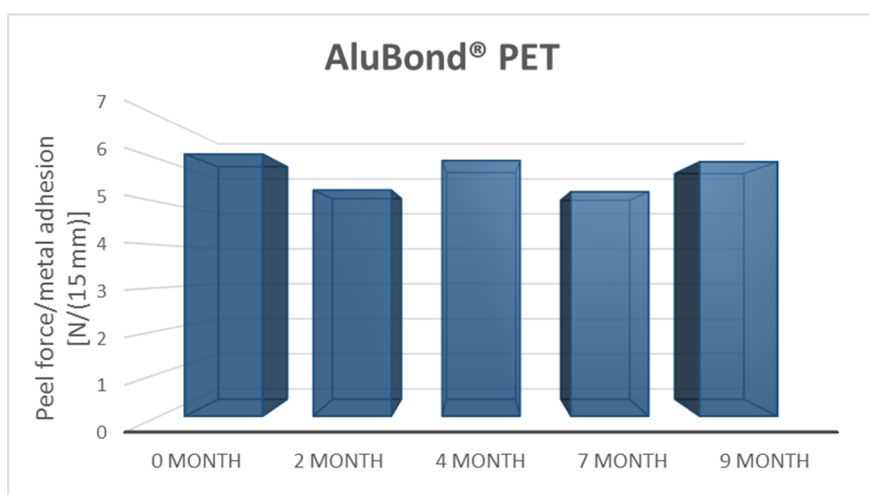


Figure 2 – Retention of adhesion over time for AluBond® PET

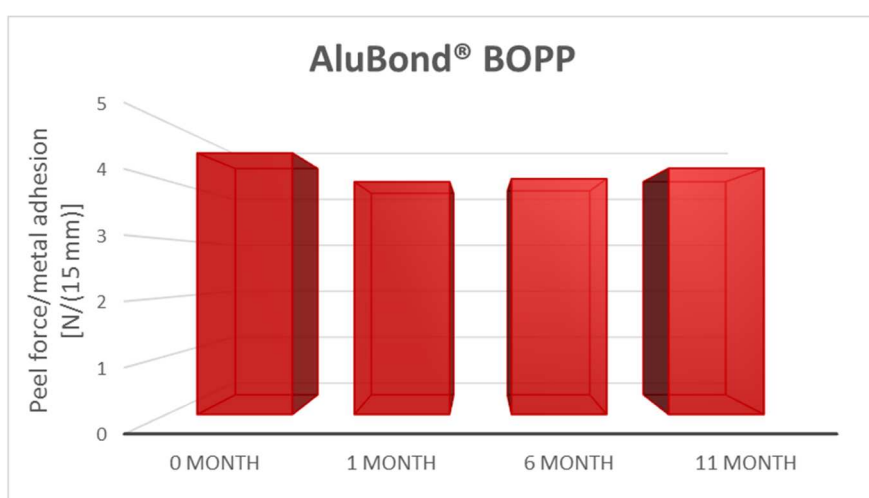


Figure 3 – Retention of adhesion over time for AluBond® BOPP

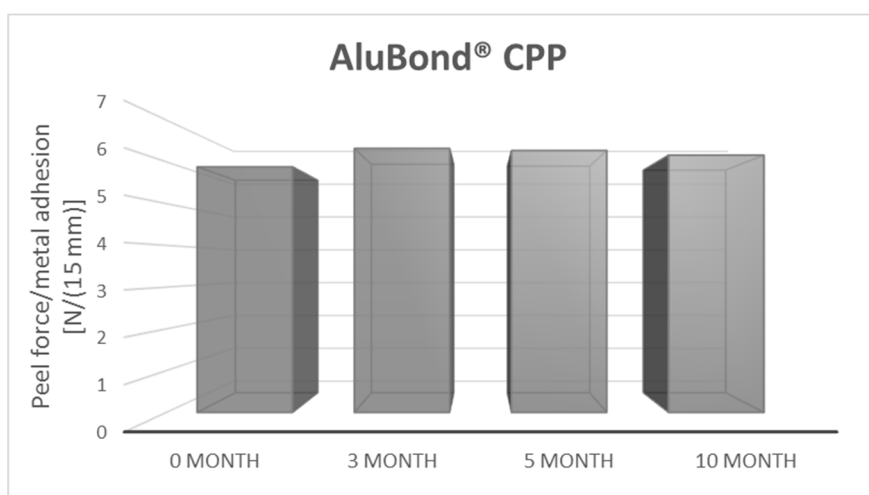


Figure 4 – Retention of adhesion over time for AluBond® CPP

AluBond® adhesion levels are, furthermore, maintained over months of sample storage (under ambient conditions) as depicted in *Figure 2* for PET, *Figure 3* for BOPP and *Figure 4* for CPP. Even at very high optical density (OD) levels, where it is typically more difficult to achieve good

adhesion levels, AluBond® offers outstanding metal adhesion properties as shown in *Table 2*. Also for the three different OD levels, the AluBond® failure mechanism was full metal removal with partial or full BOPP skin layer removal and EAA film elongation.

Table 2 – AluBond® metal adhesion results for metallized BOPP at various ODs

Structure	Description	Metal adhesion N/(15 mm)	Adhesion failure mode
BOPP/Al 20 µm	AluBond® 2.5 OD	4.27 ± 0.21	Full metal removal with partial/
	AluBond® 2.8 OD	4.11 ± 0.18	full BOPP skin layer removal/
	AluBond® 3.3 OD	3.41 ± 0.54	EAA film elongation
	Standard metal 2.7 OD	0.62 ± 0.21	Full metal removal

Finally, it should be noted that the adhesion of AluBond® metallized films can be tuned to a certain degree by changing the AluBond® intensity level (AIL). The relationship between those two parameters is depicted in *Figure 5* for a metallized 25 µm CPP film. As can be seen, the correlation between ‘treatment’ level and metal adhesion is not linear and for lower AluBond® levels, rather small improvements in metal bond strength are seen. However, from a certain point onwards, typically AluBond® level 5, a significant step change in metal adhesion is obtained, increasing the average metal adhesion by a factor of 5 for the CPP film used in this investigation (from around 0.6 N/(15 mm) for non-AluBond® to 3.1 N/(15 mm) for AluBond® level 5).

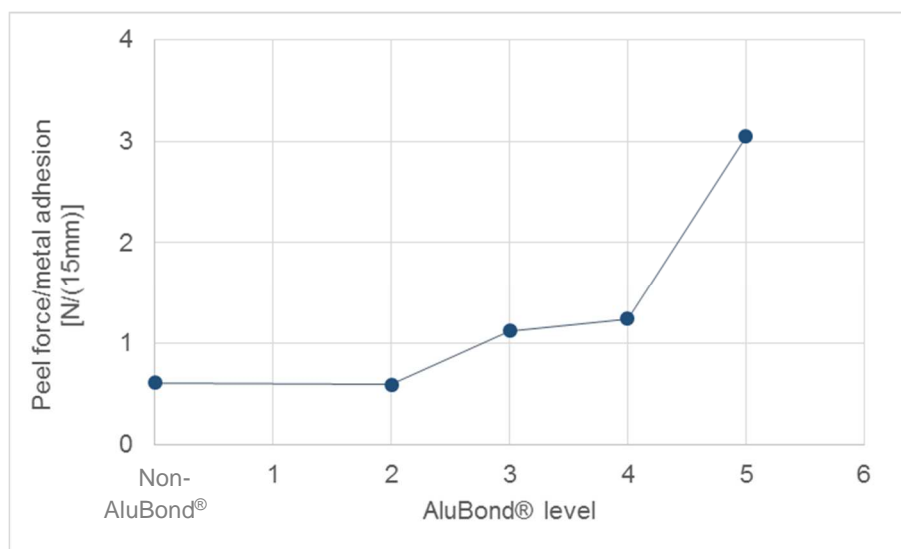


Figure 5 – Metal adhesion as a function of AluBond® level for CPP

3.2 ADHESION – LAMINATE BOND STRENGTH

In addition to the EAA peel test, laboratory adhesive lamination was carried out and metal adhesion was assessed using a 90° unsupported T-peel test as well as 180° supported peel test (comparable to the 180° EAA peel test). Whilst this is a more elaborate and time-consuming test method (due to the adhesive coating process and curing time required) and

does not give the quick results that the EAA peel test delivers, it is assumed that this may be a more representative test, since the metallized films will be laminated in their final packaging application (although this can be extrusion as well as adhesive lamination). Using the adhesive lamination method also gives the opportunity to use a thicker secondary film to laminate on top of the metal surface (in this case a 70 μm CPP film), which has a higher intrinsic strength than the 2 mil (50.8 μm) EAA film. Additionally, the adhesive layer helps as a reinforcement layer and thus avoids excessive stretching/elongation of the CPP sealant film (unlike the EAA film) during peeling, as stated by Jesdinszki et al. [10].

Results for AluBond® metallized PET and BOPP films are summarized in *Table 3*. Again, it can be seen for all tests conducted that AluBond® delivers significantly higher laminate bond strength than the non-AluBond® reference samples on the same film, which is in line with the EEA peel test results.

Table 3 – AluBond® laminate bond strength results on PET and BOPP (duplex laminate with CPP)

Structure	Description	Laminate bond	Adhesion failure mode
		strength N/(15 mm)	
180° supported peel test (50 mm/min)			
PET/Al 12 μm	Standard metal	3.03 ± 0.26	Full metal removal
	AluBond®	4.48 ± 0.49	Partial metal removal
90° unsupported peel test (100 mm/min)			
PET/Al 12 μm	Standard metal	2.19 ± 0.29	Full metal removal
	AluBond®	3.55 ± 0.34	PET film break (average max. load value given)
180° supported peel test (50 mm/min)			
BOPP/Al 20 μm	Standard metal	2.54 ± 0.08	Full metal removal
	AluBond®	5.34 ± 0.22	Partial metal removal/ CPP film delamination
90° unsupported peel test (100 mm/min)			
BOPP/Al 20 μm	Standard metal	2.69 ± 0.08	Full metal removal
	AluBond®	3.22 ± 0.27	Partial metal removal/ BOPP film break

However, the laminate bond strength of the standard metal layer is considerably higher than measured during the EAA peel test, although in both cases full metal removal is achieved (refer to *Table 1* and *Table 3*). This could possibly be caused by the heat exposure during EAA film sealing, which may weaken the metal-to-substrate bond in the case of non-AluBond® film samples and could indicate a better high-temperature resistance of AluBond® metallized film (potentially beneficial for extrusion coating/lamination). Similar to the EAA peel test, one cannot only look at the metal adhesion/laminate bond strength values obtained, but also needs to take the failure mode into account. During the 90° unsupported T-peel test, substrate film break (PET & BOPP) was typical for AluBond®. In the case of AluBond® metallized PET, the PET film tore at the start of the peel test and no actual peeling was possible (note: the laminate bond strength given is the maximum load before film break), whilst the AluBond® metallized

BOPP did peel to a certain degree until BOPP film break occurred. No material break failure was obtained when a 180° supported peel test was used. In this case, peel forces are typically higher compared to the forces measured during the T-peel test.

In addition to the duplex laminate structure, also triplex laminate structures were produced using a printed PET film (blue & white ink) and a CPP film in order to simulate higher demanding packaging applications. Results of this investigation are summarized in *Table 4*. Here, the 90° and 180° peel test deliver very similar results. In the case of non-AluBond® metallized film samples, the peel forces measured are very low and the mode of failure is nearly complete metal removal (over 90 % of the aluminum is taken off by the printed PET, with some spots of aluminum remaining on the originally metallized PET). For AluBond®, however, considerably greater peel forces (about 5 to 7 times higher) are achieved with the failure mode changing to delamination of the printed PET with a very small level of metal removal and also film break of the printed PET. In summary, these investigations prove that also in laminate structures AluBond® process technology outperforms standard metallization.

Table 4 – AluBond® laminate bond strength results on PET (triplex laminate PET/print/metPET/CPP)

Structure	Description	Laminate bond	Adhesion failure mode
		strength N/(15 mm)	
180° supported peel test (50 mm/min)			
PET/Al 12 µm	Standard metal	0.70 ± 0.22	> 90 % metal removal
	AluBond®	3.62 ± 0.21	PET print delamination/break some Al spots removed
90° unsupported peel test (100 mm/min)			
PET/Al 12 µm	Standard metal	0.51 ± 0.12	> 90 % metal removal
	AluBond®	3.91 ± 0.82	PET print delamination/break some Al spots removed

Overall it should be stated here that different adhesion measurement techniques (e.g. sealing web type, peel angle, peel speed etc.) will result in different peel force values, since the force value measured represents the energy required to break the actual bond between metal and polymer plus “the work spent in other processes, such as the inelastic deformation of the polymer” [14]. Consequently, only results obtained using exactly the same test protocol should be compared.

3.3 BARRIER PERFORMANCE

In addition to the adhesion and bond strength evaluation, AluBond® metallized samples have also been assessed for their barrier performance and results are presented in *Table 5* for metallized BOPP and CPP substrate films at different optical densities. As can be clearly seen, AluBond® process technology provides significant enhancement of oxygen as well as water vapor barrier performance. For BOPP films, OTR values are decreased to less than 10 cm³/(m² d), whilst for CPP OTRs of even less than 5 cm³/(m² d) are achieved through AluBond® metallization. Furthermore, WVTR levels < 0.1 g/(m² d) are obtained on both substrates.

Table 5 – Barrier performance of AluBond® metallized BOPP and CPP films

Structure	Description	OTR	WVTR
		cm ³ /(m ² d)	g/(m ² d)
BOPP/Al 20 µm	AluBond® 2.5 OD	8.45 ± 0.08	0.06 ± 0.01
	AluBond® 2.8 OD	5.12 ± 0.34	0.03 ± 0.01
	AluBond® 3.3 OD	4.82 ± 0.57	0.03 ± 0.01
	Standard metal 2.5 OD*	50	0.4
CPP/Al 25 µm	AluBond® 2.3 OD	3.17 ± 0.42	0.05 ± 0.01
	AluBond® 2.7 OD	2.60 ± 0.09	0.04 ± 0.01
	AluBond® 3.3 OD	2.48 ± 0.21	0.03 ± 0.01
	Standard metal 2.5 OD*	50	0.15

*Datasheet information

In addition to the tailored AluBond® coating composition boosting the barrier performance of metallized films, as seen from

Table 5, the intrinsic stability and corrosion resistance of the aluminum metal layer are also enhanced.

When assessing metallized film samples for WVTR under tropical test conditions (37.8 °C, 90 % RH gradient), it is common practice to face the metal layer away from the 90 % RH test cell half in order to avoid corrosion of the metal layer. Nevertheless, even when doing so, corrosion of the metal layer still occurs. Although not necessarily visible to the naked eye (unlike when the aluminum layer is facing the high RH side of the test cell and corrosion leads to clear areas where the aluminum has been oxidized to transparent oxide/hydroxide) the aluminum is slowly attacked, which leads to a continuous rise in the measured WVTR value and no permeation equilibrium being reached. After prolonged WVTR testing under these conditions, the attack of the metal layer can also be seen using a light microscope. In some cases, this continuous rise of WVTR can be avoided by dropping the test RH below 90 % (and calculating the WVTR for 90 % RH assuming a linear relationship). Nevertheless, we have also found that during these tests, the WVTR values frequently don't stabilize for standard metallized film and show a rising trend. When testing AluBond®, however, none of this behavior is seen; even at 90 % RH the WVTR values either stabilize or behave the opposite way and continuously drop. Figure 6 illustrates this behavior during WVTR measurement on representative samples of AluBond® and non-AluBond® metallized BOPP. As can be seen, both samples initially start at a value around 0.1 g/(m² d) on their first data point of the test graph. Nevertheless, whilst the AluBond® sample continues to drop to a value of less than 0.1 g/(m² d), the reference sample continuously rises until the test was stopped at around 0.45 g/(m² d). These results indicate that AluBond® additionally offers a more stable and less humidity/corrosion sensitive aluminum coating.

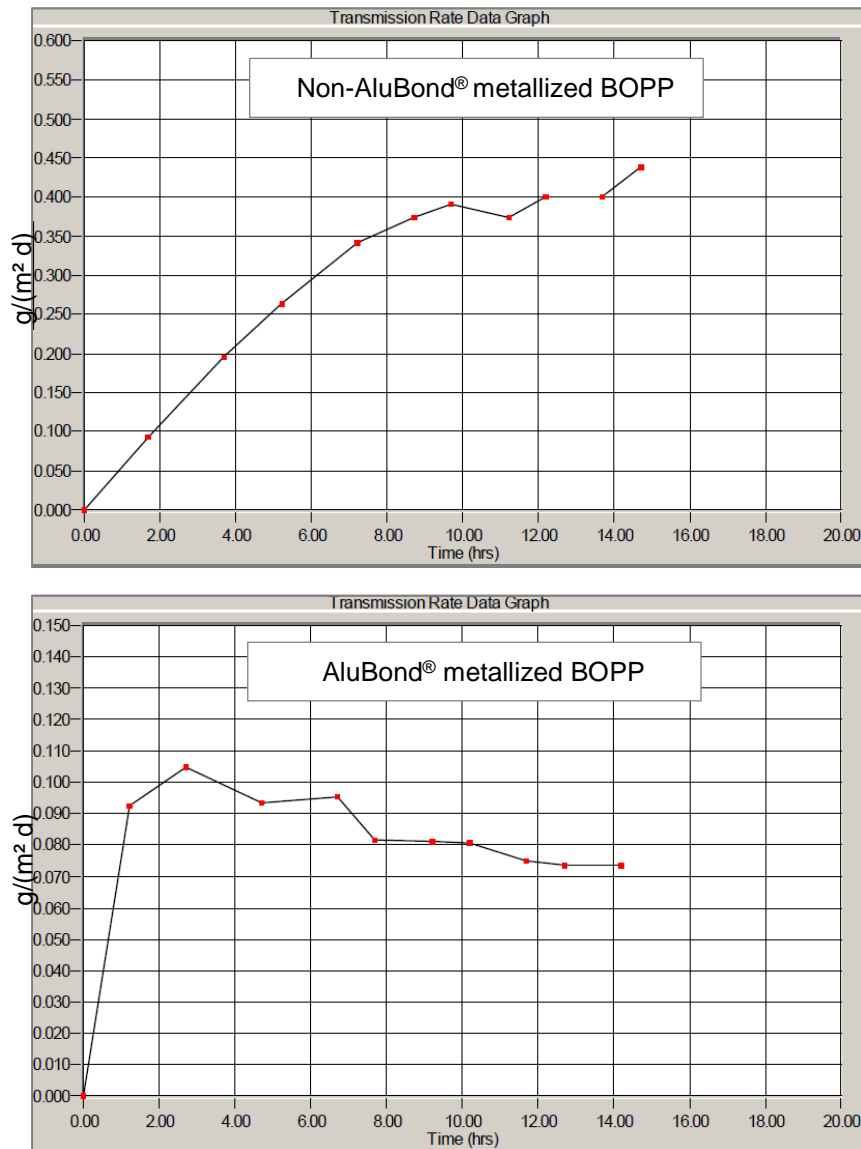


Figure 6 – Water vapor transmission rate graphs showing measurement of non-AluBond® reference (top) and AluBond® (bottom) metallized BOPP

3.4 METALLIZING DEFECTS

Samples of AluBond® metallized PET and the corresponding non-AluBond® metallized reference samples were additionally examined for metallizing defects such as pinholes/windows and starry-night using an optical microscope. Two representative images for metallized PET are depicted in Figure 7. As can be clearly seen, AluBond® had a drastic impact in reducing the smaller-sized starry-night type defects in the metallized PET film. Whilst larger pinholes/windows are visibly present for both metallized film samples, starry-night defects are completely absent for the AluBond® metallized film investigated. This suggests that the enhanced metal adhesion performance of AluBond® metallized film can reduce the likelihood of metal pickoff from small antiblock particles embedded in the film surface, which is typically assumed to be the origin of this type of defect [15].

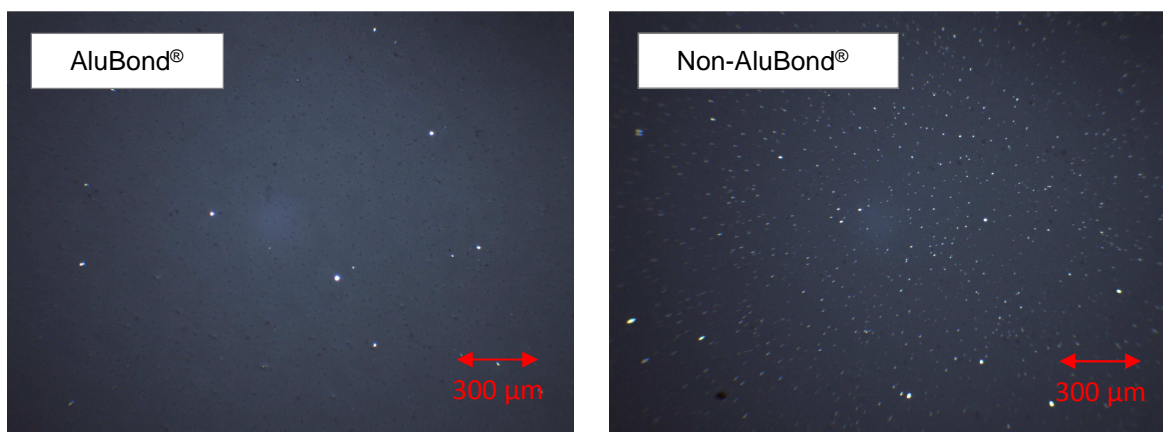


Figure 7 – Light microscope images of AluBond® metallized PET (left) and the corresponding standard metallized PET film (right)

3.5 DYNE LEVEL RETENTION

Despite one of the main properties of AluBond® being the high metal adhesion, the process technology has also shown to offer further benefit to the metallizing and converting industry in terms of higher dyne level and better dyne level retention. Unlike metallized PET films, which typically do maintain a high dyne level for longer storage periods, metallized polyolefin based films suffer from unwanted surface energy decay. This effect is considered to be caused by the transfer of mobile low-molecular-weight polymeric material (oligomers) and migratory additives (if present) from the reverse side of the coated film onto the coating, and also migration from the bulk polymer through the coating onto its surface (via defects in the coating). The freshly deposited aluminum layer would exhibit a very high surface energy (several 100 mN/m for clean metals [16, 17]) and, therefore, is extremely reactive. Consequently, the surface can readily (and rapidly) attract mobile materials and contaminants, in order to lower its surface energy. This inevitably occurs as soon as the film is wound into a roll after the coating process, and the fresh coating surface is in direct contact with the uncoated back surface of the polymer film. The process is driven by thermodynamics, with the aim to minimize the surface energy and to obtain an energetically favorable and stable state. To which extent the dyne level drops hence depends on the amount of migratable material and film additive that is available in the substrate film, the storage temperature (elevated temperatures promote quicker migration/transfer and hence faster dyne level decay) and also the glass transition temperature of the polymer film (e.g. differences between metallized PET and CPP/BOPP).

During our investigation, A4 swatch samples were kept under ambient conditions (23 ± 2 °C) and regular dyne level assessments were conducted over a period of several month. Results are shown in *Figure 8* for metallized BOPP and in *Figure 9* for metallized CPP.

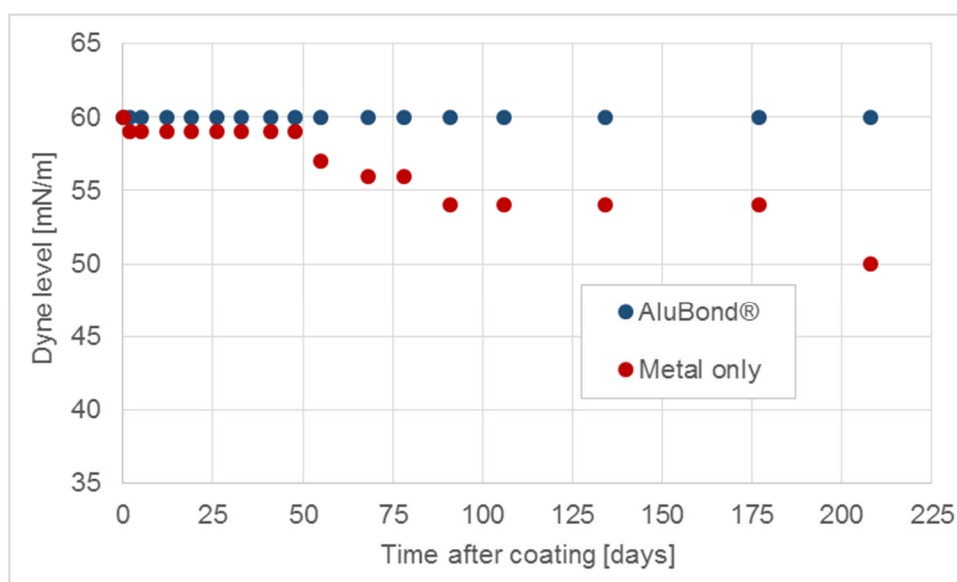


Figure 8 – Retention of dyne level over time for AluBond® metallized versus a non- AluBond® metallized BOPP film

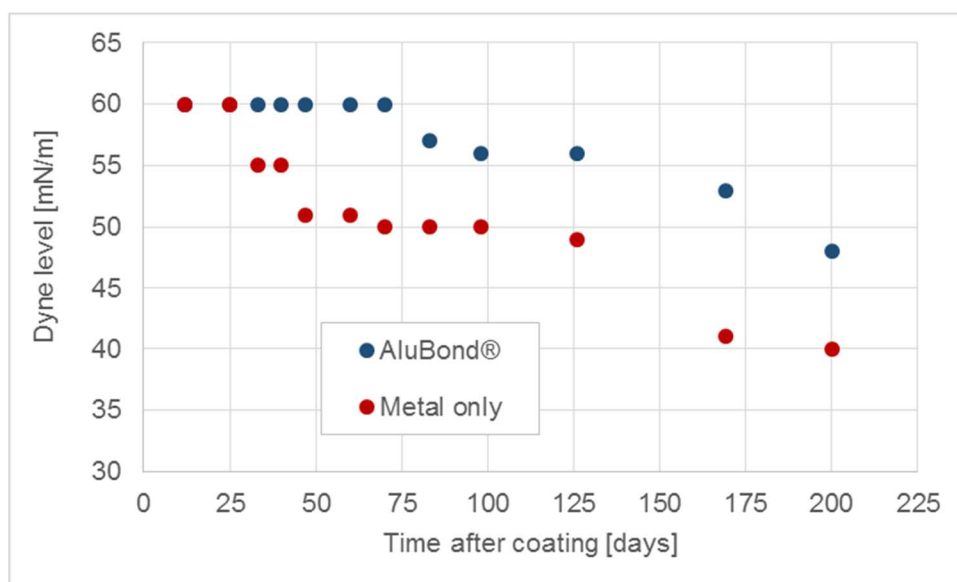


Figure 9 – Retention of dyne level over time for AluBond® metallized versus a non- AluBond® metallized CPP film

As can be clearly seen, the AluBond® metallized samples outperform the standard metallized films in that they offer an improved dyne level and maintain a higher dyne level for longer. In the case of the BOPP film, the AluBond® sample has upheld a dyne level of ≥ 60 mN/m for over 200 days, whilst the surface energy of the non-AluBond® sample has dropped to 50 mN/m in the same period of time, although both initially exhibited the same surface energy level after metallization. For the metallized CPP samples, *Figure 9* depicts that for both samples the dyne level drops with storage time; however, with AluBond® this drop is to a smaller degree. This shows that in addition to the factors affecting the dyne level of metallized films which have been stated above, also the specific characteristics of the deposited metallization layer play a critical role. The tailored stoichiometry/composition of the AluBond® metallization layer makes the coating less susceptible for polymer transfer from the reverse side of the film, thus

creating a more stable metal coating surface and promoting improved dyne level retention. This can add benefit during subsequent conversion steps such as printing, coating or lamination by initiating better ink receptivity or coating/adhesive wettability and may even eliminate the need for additional boost treatment before conversion, such as corona refresh on the laminator or printing press.

4 SUMMARY AND CONCLUSIONS

BOBST AluBond® technology has been shown to offer three main benefits to producers and converters of metallized film: significantly enhanced metal adhesion to the polymer substrate; improved barrier performance (OTR and WVTR) including moisture resistance at high relative humidity; defect reduction and enhanced dyne level together with better dyne level retention. Therefore, AluBond® technology addresses and satisfies several current market demands for enhanced performance packaging materials.

The benefit of added barrier performance for AluBond® metallized films may also eliminate the need for high optical density metallization (4 OD and higher, which is perceived to deliver better barrier properties), as similar barrier levels can be achieved at much lower OD. In this way, the thermal load to the substrate can be reduced, which is the limiting factor when metallizing heat-sensitive or thinner gauge substrates and less raw materials are required, thus reducing the overall fixed cost of the metallization process.

Moreover, with the quest for recyclability and more sustainable packing materials, there is an increasing trend of moving towards completely polyolefin based packaging structures. However, oxygen barrier levels of $\leq 1 \text{ cm}^3/(\text{m}^2 \text{ d})$, i.e. metallized PET film equivalent, are still the target, which is very difficult to achieve on non-polar polyolefin substrates and, hence, provides challenges for metallizing as well as film formulation. With the use of AluBond® technology, it is, for the first time, possible to come close to this target barrier level and further development of the AluBond® process together with film substrate optimization are likely to lead towards reaching this milestone.

5 FUTURE WORK & DEVELOPMENTS

Further characterization work is currently planned in order to assess the benefit of BOBST AluBond® process technology in combination with extrusion coating/lamination and more demanding triplex laminate applications. Also the corrosion resistance associated with AluBond® will be investigated further.

ACKNOWLEDGMENTS

The authors would like to thank the R&D and competence center staff at Bobst Manchester Ltd. for their patience and support in producing and analyzing the large amounts of trials and associated film samples required for the AluBond® development and characterization project.

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