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Packaging Paper with Overprint Varnish: Morphology, Grease Resistance, and Heat-sealing Strength

Kai Lankinen,[a,b,*] Mahdi Merabtene,[c] Esa Saukkonen,[d] and Ville Leminen,[c]

Increasing concerns regarding plastic waste and its impact on the environment have prompted a global trend to replace plastic films with fiber-based packaging solutions. Though the heat-sealing of polyolefin films provides a simple approach for realizing flexible packaging, paper does not have the natural attributes required for such applications. Therefore, paper sealability must be achieved by other means such as coating or varnishing. This study accordingly investigated the basics of imparting heat-sealability to packaging paper using overprint varnish applied with a lab coater simulating flexographic printing. The sealing and grease resistance properties of the resulting paper were compared with those of commercially available polyethylene dispersion-coated paper and oriented polypropylene/polyethylene laminate. The results confirmed that sufficient capabilities were realized using the proposed method; though the varnished paper exhibited a lower seal strength than the reference plastic films, it exhibited adequate properties for package sealing regardless of applied temperature. These observations were subsequently discussed to inform recommendations for further investigation and development.

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Contact information: a: Dr. Lankinen Graphic Innovations Ltd, Finland; b: Tampere University of Applied Sciences, Tampere, Finland; c: Lappeenranta-Lahti University of Technology LUT, Lappeenranta, Finland; d: UPM, Research and Development, Lappeenranta, Finland;
** Corresponding author: research@drlankinen.com*

INTRODUCTION

Flexible plastics are the most commonly used substrates in food packaging (Ilhan *et al.* 2021), and vertical form fill seal machines are the most common packaging machines employing flexible plastics (Dudbridge 2016). However, increasing environmental concerns along with the simultaneous focus on production efficiency and improved material properties has generated interest in new packaging solutions (Larsson and Wågberg 2016) such as bio-based materials to replace fossil-based and non-renewable plastics (Silva *et al.* 2022).

Paper can be used to eliminate plastics in many packaging applications, but as proper heat-sealability is crucial when making packaging (Aithani *et al.* 2006; Taheri *et al.* 2023), plastic-free heat-sealing solutions are required. Indeed, though heat-sealing can be made by various methods (Tiitola 2021), plain paper has yet to realize sufficient heat-sealability (Deshwal *et al.* 2019). Traditional solutions for making paper sealable involve coating the paper with a sealable plastic layer such as polyethylene (Najarzadeh *et al.* 2014) or a thin acrylic copolymer sealing layer (Hauptmann *et al.* 2021a). Another solution is to use a heat-sealing varnish to seal lids (Kesmarszky and Kick 2017). While there can be many different end uses for flexible packaging, Hauptman *et al.* (2021b) concluded that, within the parameter range considered in their study, thermoplastic materials can produce gastight packages, whereas paper-based materials cannot.

Heat-sealing is accomplished by pressing two material layers together for a specific dwell time to bond them *via* heat and pressure (Taheri *et al.* 2023). Typically, the inner layers of sealable substrates are partially melted to form this bond, though each material behaves differently and requires different sealing conditions (Merabtene *et al.* 2021). Indeed, Leminen *et al.* (2012) reported that the optimization of sealing parameters varies according to the applied material combination. According to Taheri *et al.* (2023) the seal quality and integrity are critical to product quality and safety. Aithani *et al.* (2006) reported that the two parameters most affecting the strength and quality of a heat-seal are the sealing temperature and dwell time. Furthermore, Hauptman *et al.* (2021a) observed that while temperature has a remarkable influence on sealability of polyolefins, the sealing properties of paper materials also depend on the applied pressure, dwell time, and paper moisture content. According to Andersson *et al.* (2002) heat-seal failure of a coating can also result from inadequate cohesion with the paper's pre-coating layer. Finally, Leminen *et al.* (2015) reported that the sealing pressure is a key parameter dictating the tightness of the heat-seal on paperboard trays.

Various types of sealing methods, including impulse, heat, and ultrasonic sealing, have been developed to seal different types of plastic packages (Taheri *et al.* 2023). The sealing temperature range depends on the specific properties of the employed materials: for thermoplastic film, the sealing temperature ranges from 100 to 140 °C; for paper-based heat-seal-coated materials, it ranges from 90 to 220 °C (Merabtene *et al.* 2021). Exceeding the sealing temperature will cause the seal area to become weak and thin (Taheri *et al.* 2023). According to Muller *et al.* (1998), linear low-density polyethylene materials exhibit excellent seal strength when formed at temperatures in excess of 115 °C; the present study investigated the sealing properties at lower temperatures from 90 °C.

The extrusion coating of paper with a heat-sealable polymer has become common (Vyorykka *et al.* 2011) and applying a heat-sealing varnish through printing has also been presented as an option for realizing heat-sealing. Flexographic printing, also known as "flexo printing," is a printing process that uses a flexible printing plate to transfer ink onto a substrate such as paper or plastic (Lankinen 2021) and is among the most common processes used to print packaging materials (Meyer *et al.* 2000). In this process, the printing plate, which is made of a flexible material such as a photopolymer, is wrapped around a printing cylinder inked with an anilox roller using solvent-based, water-based, or ultraviolet/electron beam curable inks, then pressed against the substrate to print an image (Kamp *et al.* 2004; Thorman 2018; Tryznowski *et al.* 2018). Flexographic printing is a versatile process that can print on a variety of substrates (Narakornpijit 2018) and produce high-quality prints with sharp images; it is also well suited for printing large areas of solid colors (Lankinen 2021) or varnishes.

Notably, grease-resistant paper materials are widely used in packaging (Koskinen 2013), as plain paper has insufficient barrier properties (Deshwal *et al.* 2019). Grease resistance is essential for packaging oily products, but while polyethylene provides a considerable good grease barrier, it complicates recycling and composting (Park *et al.* 2000). The printing of overprint varnish (OPV) on paper can improve properties such as oil and grease resistance (Leeper and Thomas 2002). Grease resistance can be tested using methods such as the KIT test TAPPI Method T559 cm-02 (Hubbe and Pruszynski 2020), the TAPPI T-507 test (Ma *et al.* 2015; Park *et al.* 2000), or a modified ISO 16532-1 procedure (Ovaska 2016).

The purpose of this study was to evaluate the possibility of making grease-resistant sealable paper using an OPV applied via flexographic printing. The flexographic printing process was simulated by applying a flexographic printing varnish to packaging paper using a lab coater. The performance of flat-type heat-seals made using different process parameters were subsequently evaluated, and the properties of the resulting seals were compared with those achieved using traditional heat-sealing solutions. The results indicate that the ability to print paper with heat-seal functionality offers enhanced opportunities for realizing superior efficiency and flexibility when producing small batches and various types of packaging using a flexographic printer. The printing option also allows applying heat-seal varnish only on sealing areas, thereby reducing coverage and improving cost efficiency and sustainability.

EXPERIMENTAL

Test Materials and Specimen Preparation

The sample materials evaluated in this study are listed in Table 1; they include a conventional heat-sealable thermoplastic oriented polypropylene/polyethylene (OPP/PE) laminate material (*i.e.*, the reference film), a polyethylene heat-sealable dispersion-coated paper (*i.e.*, the reference paper), and a dispersion-coated paper printed with three different types of flexographic varnish coatings. Many different types of sealing techniques can be used, but this study employed a flat sealing tool to investigate the sealing properties achieved with different temperatures and dwell times (Aithani *et al.* 2006).

Table 1. Test Materials

Reference film	OPP/PE film (15/2/35 µm) with a 52 µm total thickness
Reference paper	UPM Confidio™ 65 g/m^2 heat-sealable, polyethylene dispersion-coated paper
Dispersion-coated paper	UPM Asendo™ 65 g/m^2 one-side dispersion-coated barrier paper, a non-heat-sealable product
Varnish 1	Water-based heat-seal coating with a solid content of 26 %, recommended wet film weight of 12 to 15 g/m^2, recommended dry film weight of 3 to 6 g/m^2, density of 1005 kg/l, and recommended activation temperature of 70 to 130 °C for 0.5 s at 1 to 8 bar
Varnish 2	Water-based heat-seal coating with a solid content of 45 %, recommended wet film weight of 12 to 15 g/m^2, density of 1030 kg/l, and recommended activation temperature of 140 to 160 °C for 0.5 s at 3 bar
Varnish 3	Water-based primer with a solid content of 60 % and density of 1.000 kg/l

The sealable paper specimens were produced by coating UPM Asendo™ 65 g/m^2 dispersion-coated barrier paper from UPM Specialty Papers with one of three water-based heat-sealing varnishes using a 12 µm coating thickness rod on an RK Print-Coat lab coater, as shown in Fig. 1. According to UPM: “the Asendo™ is a C1S paper with a good mineral oil barrier and grease and moisture resistance. It is safe for food, recyclable, and compostable” (UPM Asendo^{TM} 2022). The technical specifications of this paper are shown in Table 2; where KIT refers to assessing the level of repellency and/or antiwicking properties, WVTR stands for Water Vapor Transmission Rate, and RH for Relative Humidity.

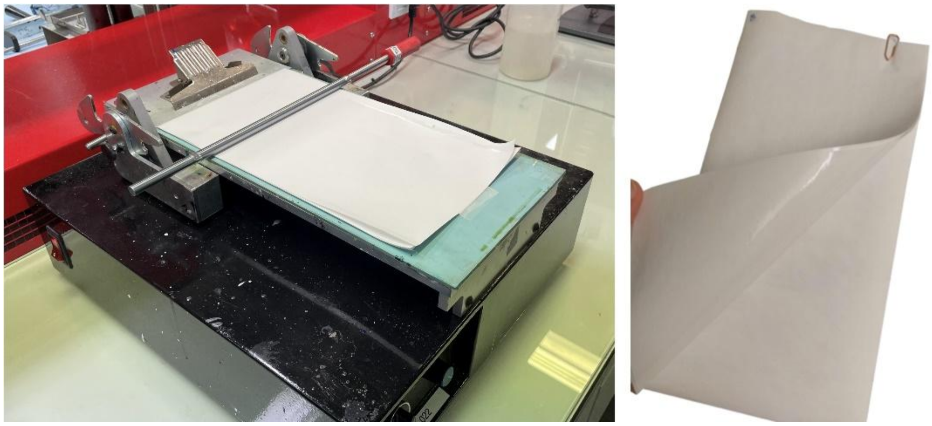

Fig. 1. RK Print-Coat lab coater with a 12 μm rod (left) and a one-side coated paper specimen (right)

Table 2. UPM Asendo™ Barrier Paper Properties

Basic Weight (ISO 536) (g/m²)	65.0
Thickness (ISO 534) (μm)	66.0
Brightness C/2° (ISO 2470) (%)	76
Opacity (ISO 2471) (%)	77
Grease resistance (KIT top)	6
WVTR 23 °C / RH 50 % (g/m²/d)	20
Mineral oil barrier	Ok

The properties of the commercially available varnishes are presented in Table 1, and the three different coating combinations applied using these materials are detailed in Table 3. In each case, the first coating layer was allowed to dry for 3 min at 20 °C before the second coating layer was applied.

Table 3. Heat-seal Coatings Applied to the Barrier Paper (UPM Asendo^{TM} 2022)

OPV A	Two 12 μm layers of Varnish 1.
OPV B	Two 12 μm layers of Varnish 2.
OPV C	One 12 μm layer of primer Varnish 3 and one 12 μm layer of Varnish 2.

The packaging performances of the three coated paper samples were compared with those of traditional packaging solutions, denoted the reference laminate and reference paper in Table 2. The OPP/PE reference laminate was manufactured by Tecnopack Univel S.R.L. to provide a 35 μm OPP layer on the outside and a 15 μm PE sealing layer on the inside. The technical specifications of the OPP/PE laminate are shown in Table 4; a scanning electron microscope (SEM) cross-section image of the OPP/PE reference laminate is presented in Fig. 2, which is reproduced from Merabtene *et al.* (2023).

Table 4. OPP/PE Laminate Reference Properties

Basic weight (ASTM D-374) (g/m²)	49.65 ± 6 %
Thickness (DIN 53352) (μm)	52 ± 6 %
Polyethylene coating (g/m²)	35 ± 6 %

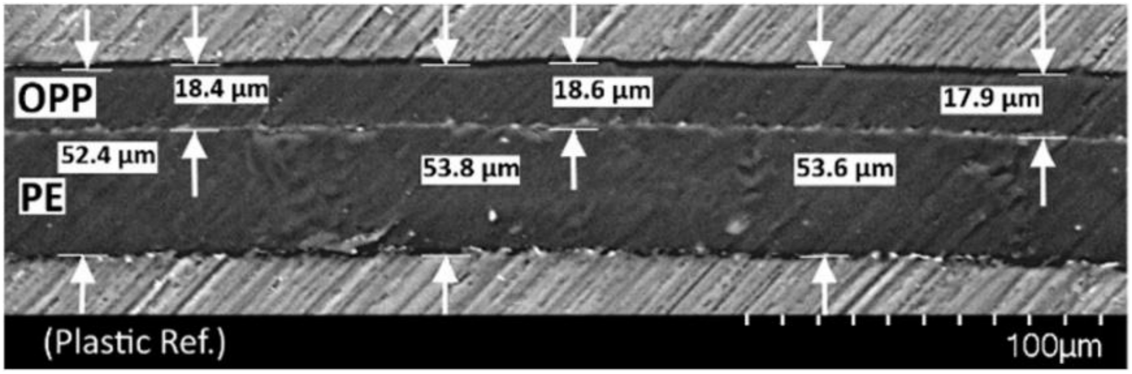

Fig. 2. SEM cross-section image of OPP/PE reference laminate (Merabtene *et al.* 2023, Creative Commons CC BY)

The coated heat-sealable reference paper was UPM Confidio™, “a heat-sealable and recyclable C1S barrier paper, offering a very good moisture barrier, good grease resistance, and a mineral oil barrier” manufactured by UPM Specialty papers. (UPM Confidio™ 2022). The technical specifications of the UPM Confidio™ paper are shown in Table 5, and an SEM cross-section image of the UPM Confidio™ paper is presented in Fig. 3, which is reproduced from Merabtene *et al.* (2023).

Table 5. UPM Confidio™ Paper Properties (UPM Confidio™ 2022)

Basic Weight (ISO 536) (g/m²)	65.0
Thickness (ISO 534) (µm)	66.0
Brightness C/2° (ISO 2470) (%)	76
Opacity (ISO 2471) (%)	77
Grease resistance (KIT top)	7
WVTR 23 °C / RH 50 % (g/m²/d)	150
Mineral oil barrier	Ok

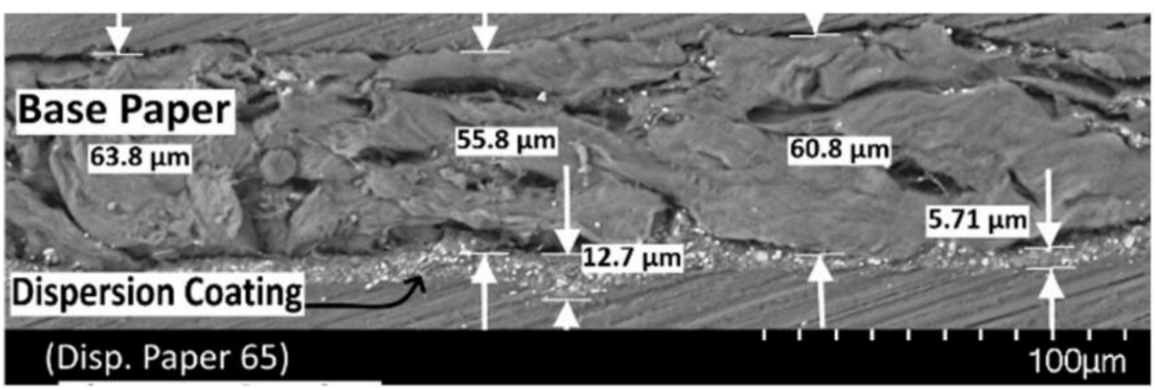

Fig. 3. SEM cross-section image of UPM Confidio™ 65 g/m2 polyethylene dispersion-coated heat-sealable reference paper (Merabtene *et al.* 2023, Creative Commons CC BY)

All specimens were conditioned for 24 h at 23 °C and 50 % relative humidity before conducting the heat-sealing and oil and grease resistance tests.

Test Methods

All paper specimens were imaged by SEM using a Hitachi SU3500 operated in variable pressure mode and by backscatter electron imaging in compositional mode to obtain high quality micrographs of the fibers. The selected acceleration voltage, pressure, and working distance were 15 kV, 30 Pa, and 10 mm, respectively. For the surface micrographs, secondary imaging was used with an acceleration voltage and working distance of 15 kV and 10 mm, respectively. The surfaces of all specimen materials were sputter-coated with Au/Pd target. Thickness and grammage measurements were conducted according to ISO 534 and ISO 536, respectively. The Messmer Büchel model 49-56 digital micrometer was used to measure the layer thickness with an accuracy of one micrometer and is shown in Fig. 4.

Fig. 4. Messmer Büchel model 49-56 digital micrometer used for thickness measurement

The grease resistance measurements of specimens OPV A–C were performed according to a modified ISO 16532-1 procedure using 150 µL of vegetable oil at 23 °C and 50 % relative humidity, as shown in Fig. 5. The vegetable oil was applied through a hole in the sample test holder using a digital pipette, and a 50 g weight was included in the holder to provide force promoting grease penetration. The grease penetration effect was subsequently evaluated in a heating chamber at 60 °C for the time intervals specified in Table 6, and the maximum and minimum times for penetration were recorded.

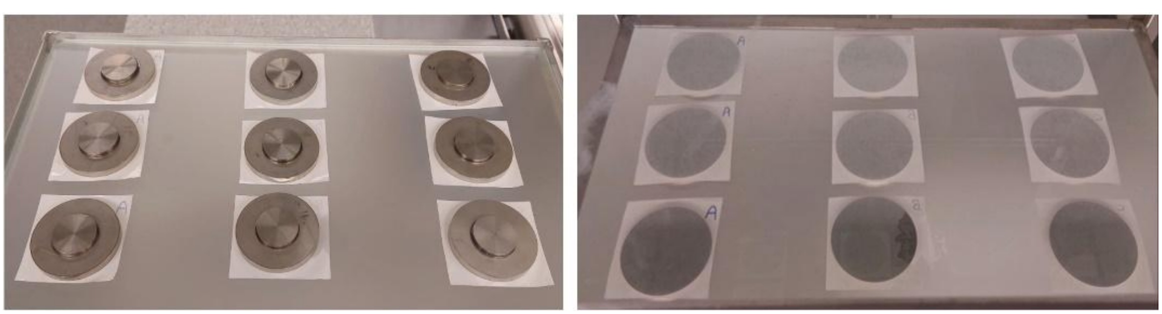

Fig. 5. Test arrangement according to modified ISO 16532-1 to evaluate grease resistance. The left image shows the samples on the top of a glass table with 150 µl of vegetable oil added to the center of the holders and the right image shows the inspection mirror below the sample table.

Table 6. Evaluation of Grease Resistance According to ISO 16532-1

Time Period	Interval for Evaluation
0 to 10 min	Every 1 min
10 to 30 min	Every 2 min
30 to 60 min	Every 5 min
60 min (1 h)	Every 10 min
2 to 6 h	Every 1 h

The material specimens were heat-sealed using 25 mm wide flat sealing jaws (metal vs. metal) on an RDM HSB-1 Laboratory Heat Sealer, as shown in Fig. 6. The temperature was applied to both sides of the seal in 10 °C increments from 90 to 160 °C while applying a pressure of 5 bar for 0.3 s, 0.5 s, or 1.0 s dwell times. The resulting seal sample was 25 mm wide.

Fig. 6. RDM heat-sealer (left) and heat-sealing of a sample (right)

The 25 mm heat-seal test specimens were subsequently prepared according to ASTM F88 to conduct 180° T-peel tests using a Shimadzu AGS 1 kN Precision Universal Tester, as shown in Fig. 7.

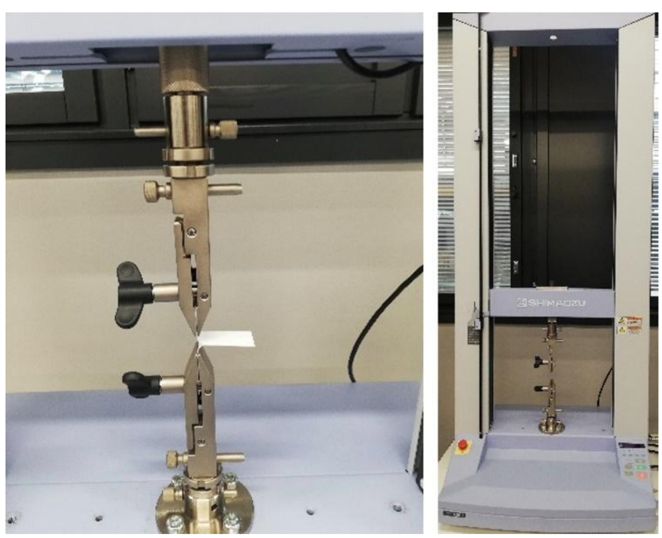

Fig. 7. Heat-seal strength test (left) and Shimadzu Universal Tester (right)

RESULTS AND DISCUSSION

Thickness and Grammage

The thickness and grammage measurement results are shown in Table 7, in which the data for the dispersion-coated reference paper were taken from the technical data sheet for the paper substrate.

Table 7. Thickness and Grammage Measurements of the Samples According to ISO 534 and ISO 536

Sample	Thickness	Grammage
OPV A	71 µm ± 0.511	71.5 g/m^2 ± 5 %
OPV B	73 µm ± 0.449	76.5 g/m^2 ± 5 %
OPV C	73 µm ± 0.655	79.5 g/m^2 ± 5 %
Dispersion-coated reference paper	66 µm ± 0.831	65.0 g/m^2 ± 5 %

According to the measurements, the OPV A specimen exhibited a thickness of 71 µm and a grammage of 71.45 g/m^2, indicating that the two 12 µm wet coats of Varnish 1 added 5 µm of dry coating thickness and an average 6.45 g/m^2 of grammage. According to the Varnish 1 product specification, the recommended dry film weight ranges from 3 to 6 g/m^2, indicating that the applied dry weight of 6.45 g/m^2 was approximately as recommended. Furthermore, this value is extremely close to the theoretical calculation, which indicated that two layers of 12 µm wet film thickness with a 26 % dry content should result in an additional grammage of 6.27 g/m^2 given a Varnish 1 density of 1005 kg/m^3.

The OPV B specimen exhibited thickness of 73 µm and grammage of 76.37 g/m^2, indicating that two 12 µm wet coats of Varnish 2 added 7 µm of dry coating thickness and an average 11.37 g/m^2 of grammage. According to the Varnish 2 product specification, the recommended dry film weight was as high as 10.38 g/m^2, which is generally consistent with the applied dry weight of 11.37 g/m^2 and is extremely close to the theoretical calculation, which indicated that two layers of 12 µm wet film thickness with a 45% dry content should result in an additional grammage of 11.12 g/m^2 given a Varnish 2 density of 1030 kg/m^3.

The OPV C specimen exhibited a thickness of 73 µm and a grammage of 79.60 g/m^2, indicating that the 12 µm wet coat of Varnish 2 and 12 µm wet coat of Varnish 3 added 7 µm of dry coating thickness and an average grammage of 14.60 g/m^2. According to the Varnish 2 and Varnish 3 product specifications, the recommended dry film weight was as high as 12.11 g/m^2, indicating that the applied dry weight of 14.60 g/m^2 was slightly larger than recommended. However, this value is close to that obtained by theoretical calculation, in which one 12 µm wet layer of Varnish 3 with a 60% dry content and one 12 µm wet layer of Varnish 2 with a 45 % dry content were expected to result in an additional 12.60 g/m^2 given a Varnish 3 density of 1000 kg/m^3.

These results indicate that OPV B provided 2 µm more thickness and 4.92 g/m^2 higher grammage than OPV A, while OPV C provided 2 µm more thickness and 8.15 g/m^2 higher grammage. This was expected since the solid contents of Varnishes 1, 2, and 3 were 26 %, 45 %, and 60 %, respectively.

Grease Resistance

The images of the grease test specimens before the test and after 24 h are presented in Figs. 8 and 9, respectively. The results demonstrated that all varnished paper specimens exhibited no grease leakage after 10 min, indicating that all the samples were grease resistant. Upon further monitoring, leak failures were noticed as shown in Table 8 and Fig. 9. Note that the third OPV B sample exhibited an accidental failure in the beginning, as shown in Fig. 8, and was accordingly excluded from this analysis.

The grease resistance test results demonstrated that the application of the heat-seal varnish also improves the grease resistance of the paper substrate. The results are logical, since OPV A had the thinnest coating, which could leave room for pinholes. The subsequent leakage of OPV B is also logical, since it had approximately twice the dry content of OPV A and therefore provided fewer opportunities for pinholing and leaks. However, OPV C had a primer as its first coating layer, which improved the wetting of the varnish applied in the second layer, resulting in the highest coating weight. Thus, OPV C exhibited few if any pinholes and remained grease resistant throughout the 24 h test period.

Table 8. Observations from the Grease Resistance Test

Time	OPV A	OPV B	OPV C
After 10 min	No leakage	No leakage	No leakage
After 30 min	First leak, tiny spot	First leak, a bit larger spot than for OPV A	No leakage
After 60 min	Leak remained generally unchanged	Second leak, and the first leak grew slightly	No leakage
After 2 h	Leak became a bit larger, and a new leak was observed	Leak became larger	No leakage
After 6 h	Leak remained generally unchanged	Leak remained generally unchanged	No leakage
After 24 h	Leaks appeared in upper and lower specimens	Upper specimen remained grease resistant, but lower specimen did not	No leakage
Summary	Tiny spot (leak) appeared after 16 min	Tiny spot (leak) appeared after 21 min	No leakage, sample remained grease resistant

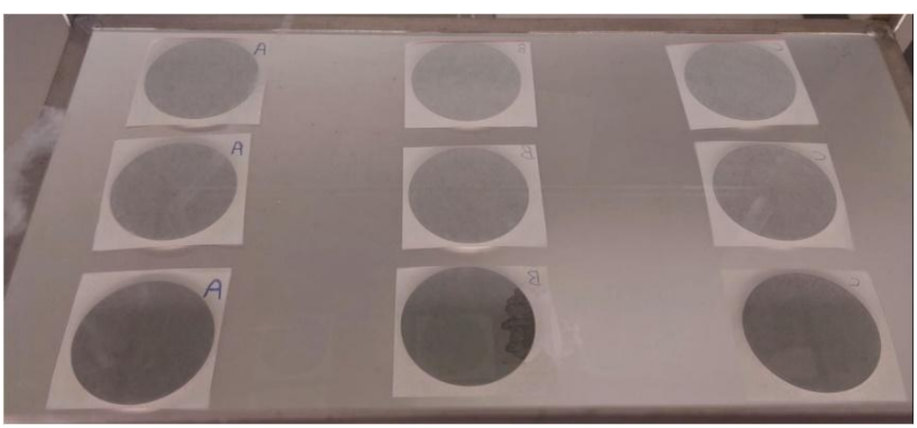

Fig. 8. Grease resistance test in the beginning (0 min)

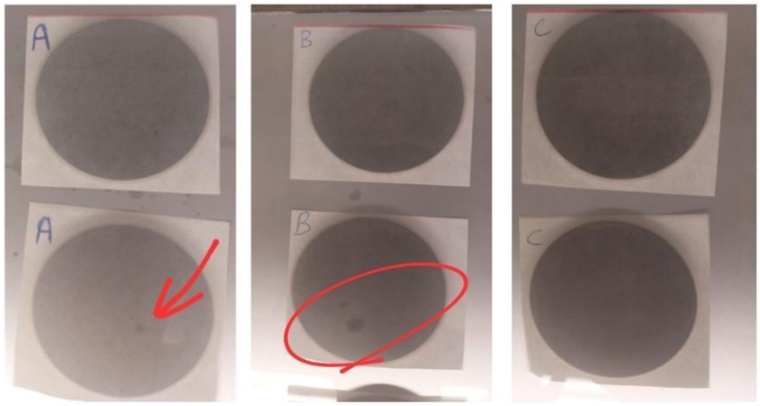

Fig. 9. Grease resistance test after 24 h. The OPV A upper test piece and lower test piece were not grease resistant. OPV B's upper sample remained grease resistant, but the lower one did not. OPV C was grease resistant after 24 h.

SEM Images

The SEM images of the specimens taken at a 40° angle, shown in Fig. 10, clearly illustrate how the smoothness of the specimen surface increased with the coating thickness.

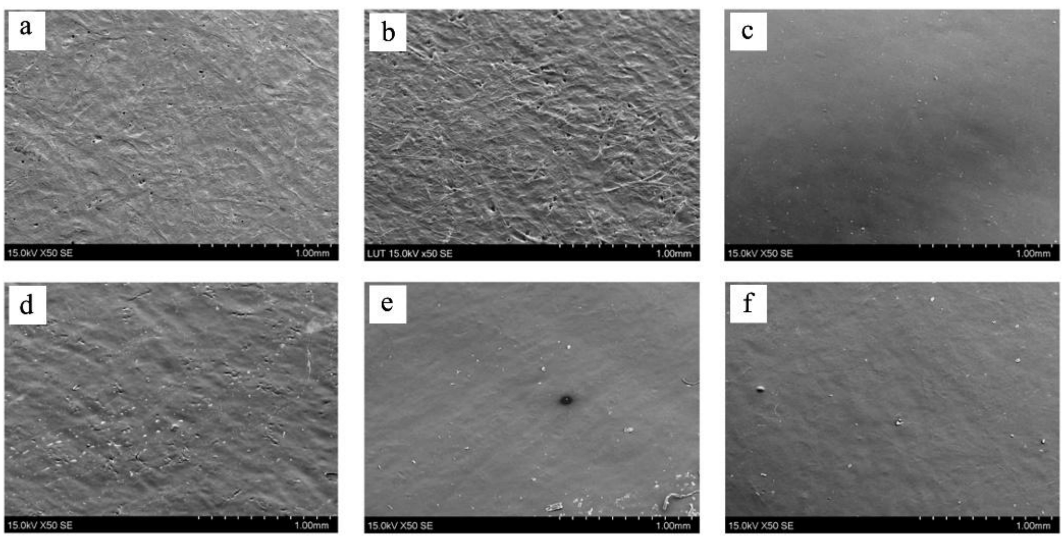

Fig. 10. SEM images of the specimen surfaces taken at 40°: a) UPM Asendo™ dispersion coated paper (no heat-seal), b) UPM Confidio™ dispersion coated reference paper (heat-seal), c) OPP/PE 52 µm thick reference film, d) OPV A, e) OPV B, f) OPV C

Figure 11 shows the SEM cross-sections of the specimens, illustrating how the OPV was applied to the coated side of the paper. In Fig. 11(f), the coating of the paper is primarily missing, but the OPV is still visible.

Heat-sealing Tests

The seal strength test results for all substrates sealed using dwell times of 0.3, 0.5, and 1.0 s are shown in Figs. 12, 13, and 14, respectively. The OPP/PE reference film exhibited a remarkably higher seal strength than the heat-sealable dispersion-coated reference paper or any of the varnish-coated papers (OPV A, B, or C). Linear low-density polyethylene materials can achieve excellent seal strength when subjected to temperatures higher than 115 °C, which was also observed in this study for the OPP/PE reference film

(Mueller *et al.* 1998). The varnish-coated specimens exhibited excellent sealing properties at lower temperatures of 90 to 100 °C, whereas neither the OPP/PE reference film nor the dispersion-coated reference paper exhibited a suitable seal strength.

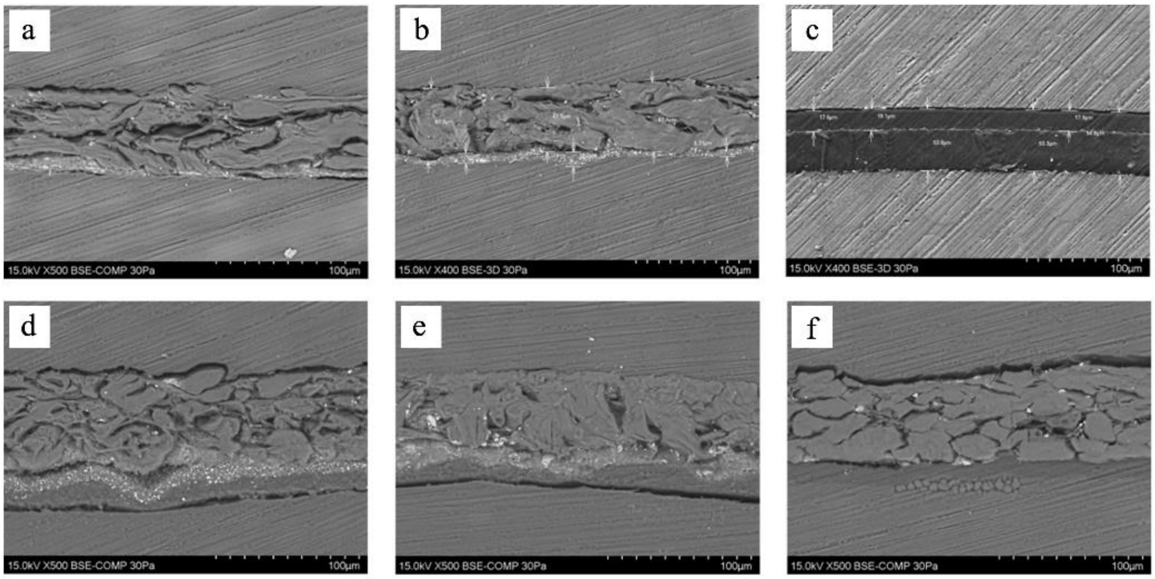

Fig. 11. Cross-sectional images of the test materials with scanning electron microscope: a) UPM Asendo™ dispersion coated paper (no heat-seal), b) UPM Confidio™ dispersion coated reference paper (heat-seal), c) OPP/PE 52 µm thick reference film, d) OPV A, e) OPV B, f) OPV C

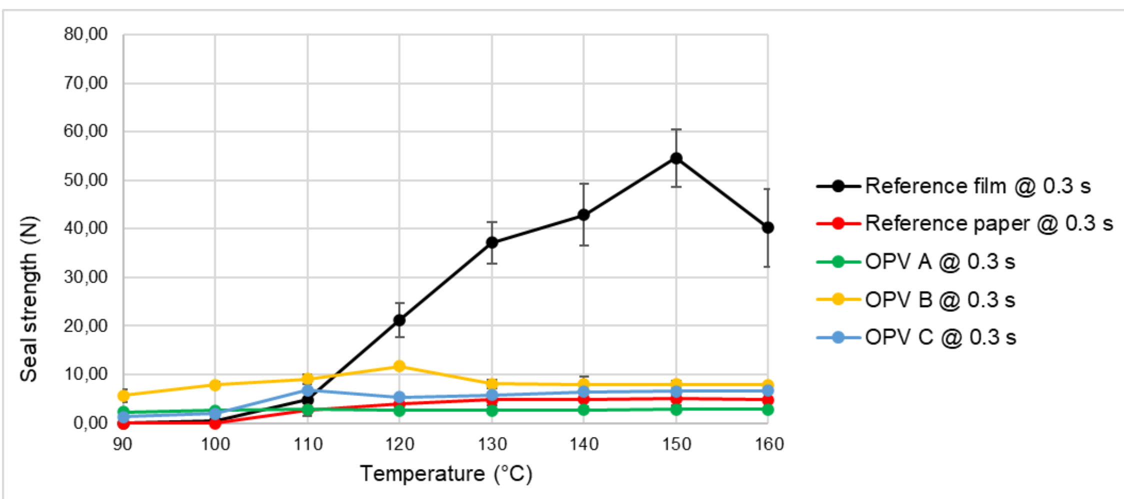

Fig. 12. Seal strength test results for a dwell time of 0.3 s

Indeed, OPV B exhibited the highest seal strength at these temperatures regardless of dwell time. At sealing temperatures from 110 to 160 °C, the OPP/PE reference film exhibited the best seal strength, though it dropped dramatically at 160 °C; the other specimens exhibited a constant seal strength regardless of temperature. In summary, OPV B (two 12 µm layers of Varnish 2) consistently demonstrated the highest seal strength among the varnish-coated specimens (as well as the dispersion-coated reference paper), whereas OPV C exhibited the lowest seal strength.

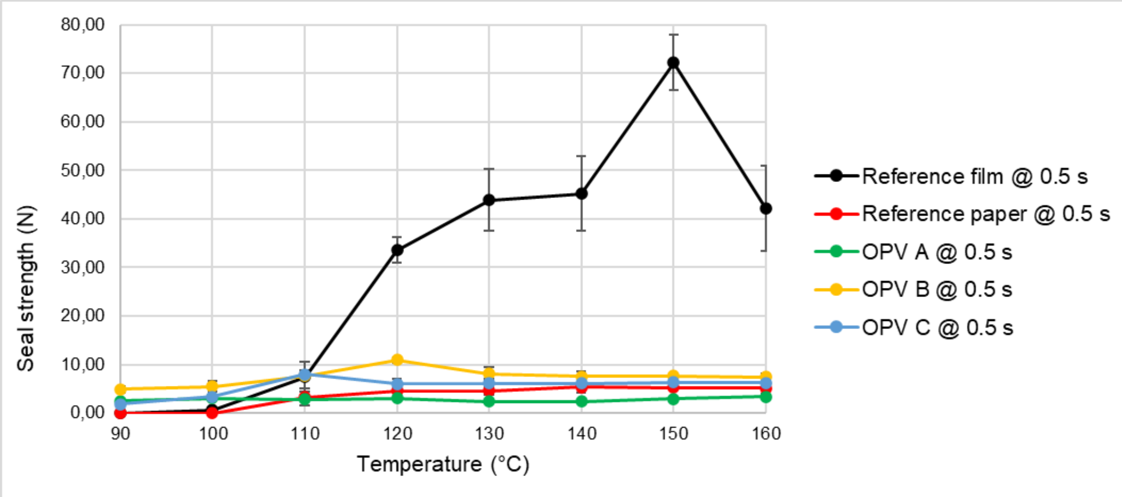

Fig. 13. Seal strength test results for a dwell time of 0.5 s

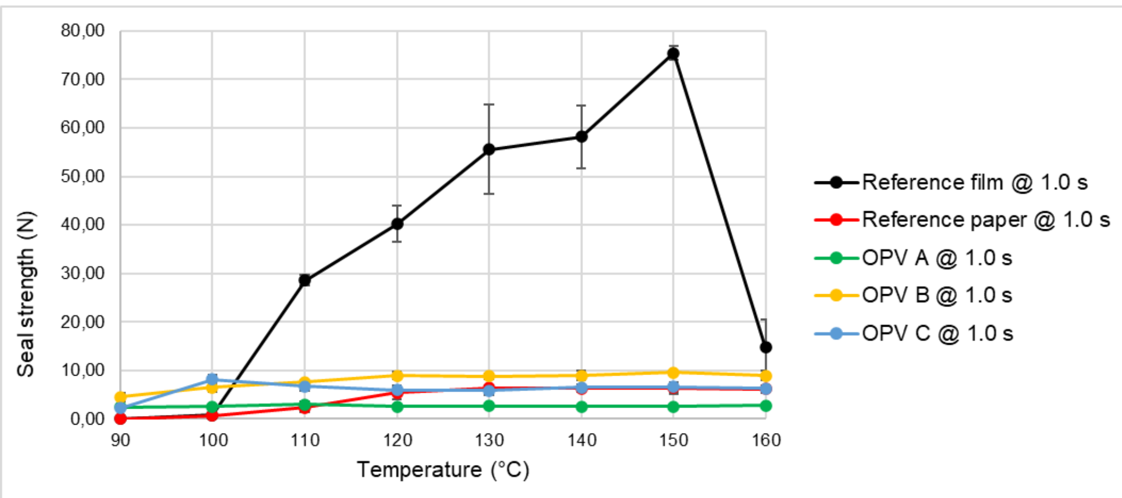

Fig. 14. Seal strength test results for a dwell time of 1 s

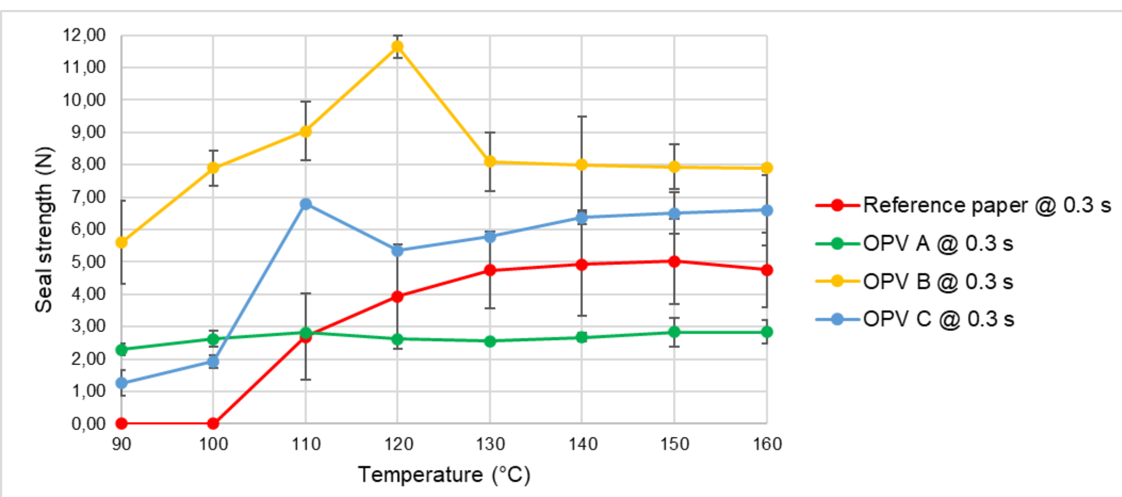

Fig. 15. Seal strength test results for a dwell time of 0.3 s (papers only)

Owing to the considerable difference between the seal strengths of the OPP/PE reference film and the other papers at temperatures from 110 to 160 °C, Figs. 15 to 17 present the seal strength results for the papers only to facilitate a more detailed analysis of the seal performances.

Clearly, OPV B exhibited the best sealing strength of all varnish-coated papers as well as the dispersion-coated reference paper over the temperature range from 90 to 160 °C for all evaluated dwell times. The OPV A specimens likely exhibited lower seal strengths owing to their lower coating weights compared to OPV B and OPV C.

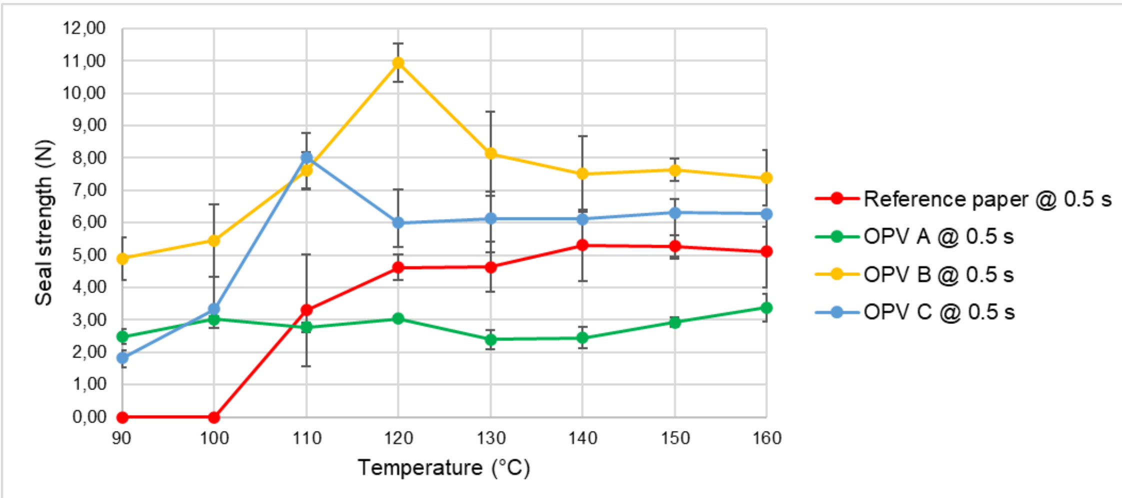

Fig. 16. Seal strength test results for a dwell time of 0.5 s (papers only)

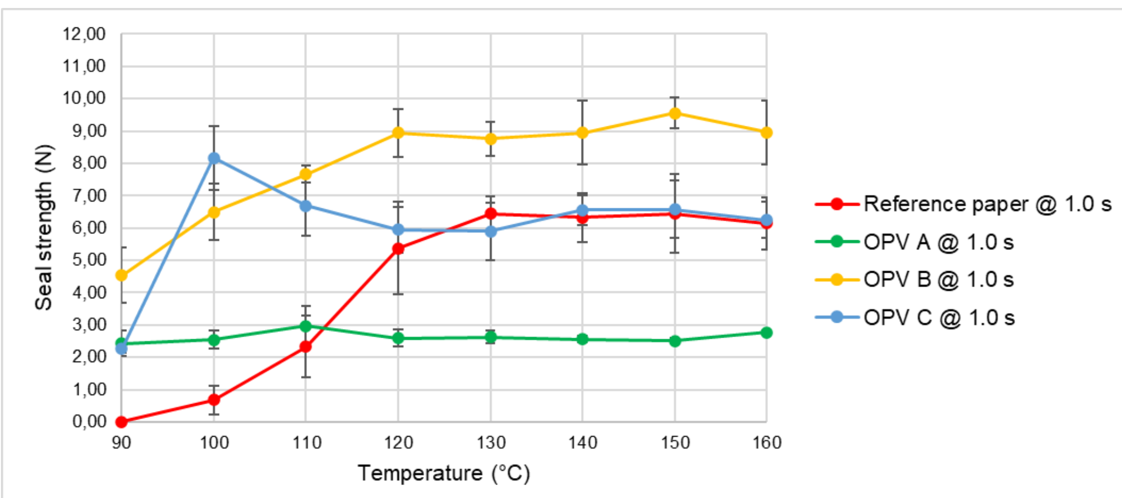

Fig. 17. Seal strength test results for a dwell time of 1 s (papers only)

To enable further examination of each specimen's characteristics and behavior according to dwell time, the seal strengths of the OPP/PE reference film, dispersion-coated reference paper, OPV A, OPV B, and OPV C specimens were compared under each dwell time as shown in Figs. 18, 19, 20, 21, and 22, respectively.

The seal strength of each varnish-coated specimen as well as the dispersion-coated reference paper remained relatively consistent across all dwell times. The seal strength of OPV A remained consistent and relatively low regardless of temperature or dwell time, that of OPV B exhibited suitable performance under all conditions and was particularly consistent between 110 to 160 °C. Though OPV C also exhibited relatively high seal strength values, they were smaller than those of OPV B. However, a significant increase in seal strength was observed for the OPP/PE reference film as the dwell time increased from 0.3 to 1.0 s when subjected to temperatures ranging from 110 to 150 °C.

While the OPP/PE reference film exhibited the highest seal strength at elevated temperatures – especially between 120 °C and 160 °C – it had a narrower sealing window at temperatures below 100 °C. This observation aligns with the findings of Hauptmann *et al*. (2021a).

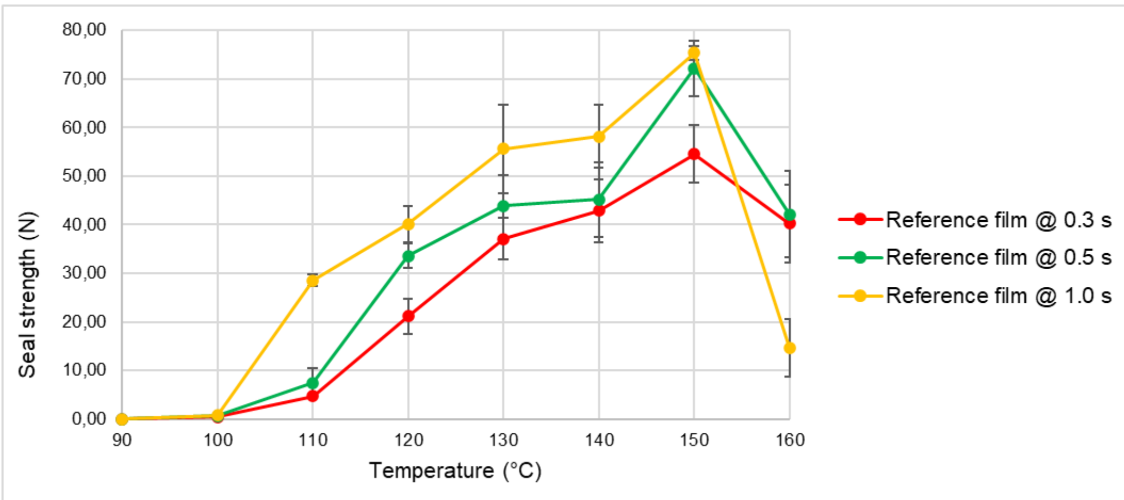

Fig. 18. Seal strength test results for reference OPP/PE

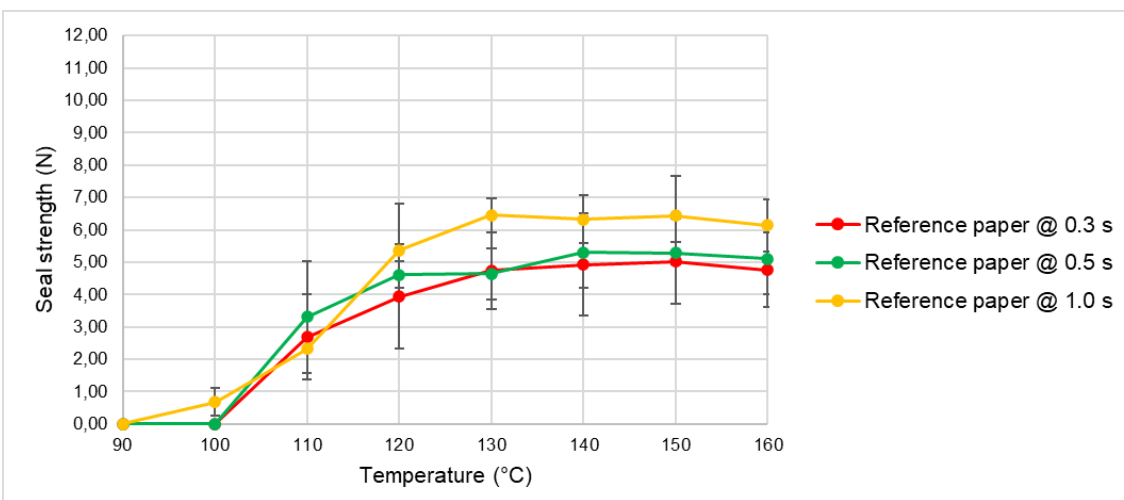

Fig. 19. Seal strength test results for dispersion-coated reference paper

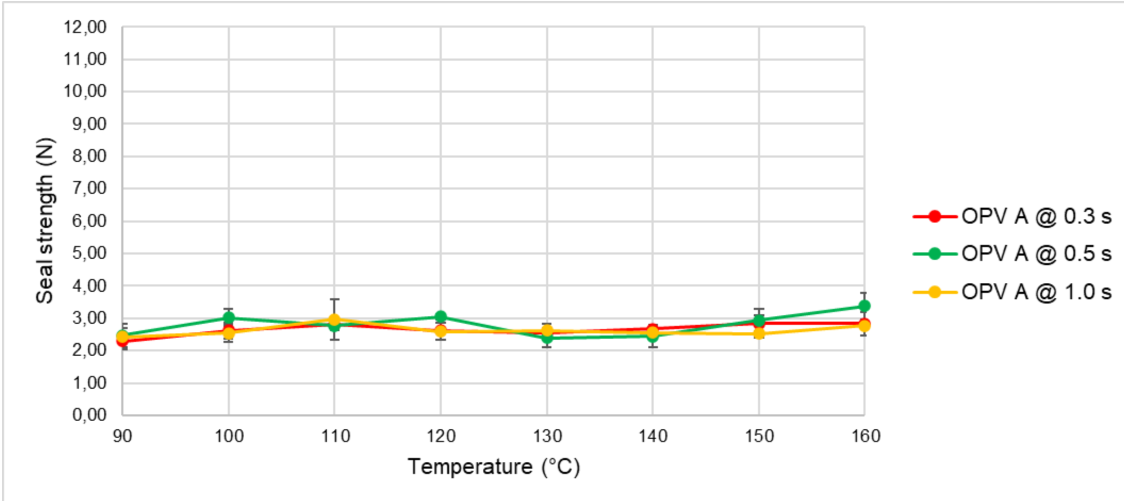

Fig. 20. Seal strength test results for OPV A

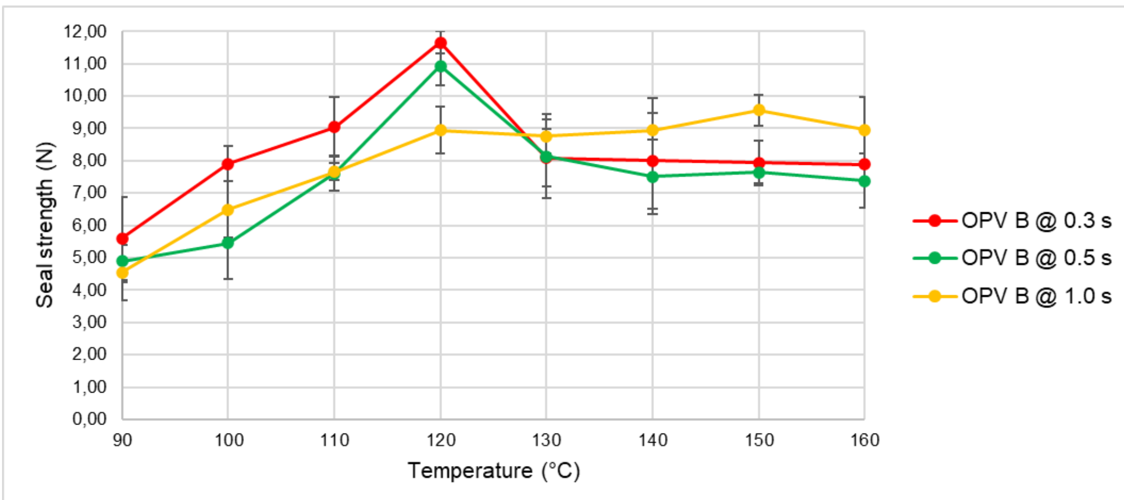

Fig. 21. Seal strength test results for OPV B

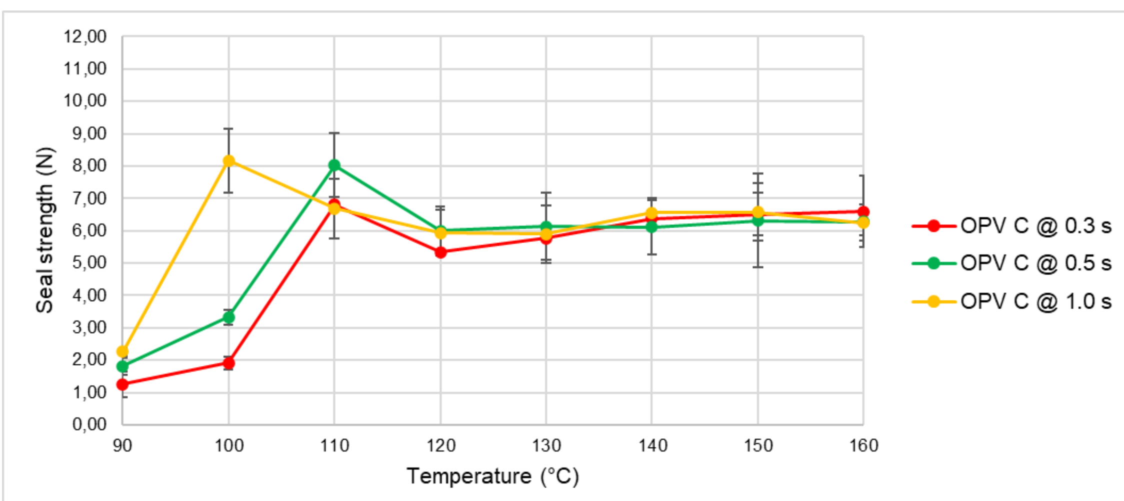

Fig. 22. Seal strength test results for OPV C

Suggestions for Future Research

The possibility of producing heat-sealable packaging paper by overprinting a varnish using flexographic printing can expand printers' options for converting paper into diverse products. Therefore, it would be interesting to see how such coated samples perform when manufactured using realistic commercial production methods. In particular, developing an understanding of the influence of varnish coating thickness and the number of applied coating layers could provide valuable insights into the parameters required for successfully applying a heat-sealing varnish coating to paper using flexographic printing.

CONCLUSIONS

1. The overprint varnish (OPV) coated papers generally exhibited lower seal strengths than the plastic film. However, several OPV specimens exhibited higher seal strengths than the heat-sealable dispersion-coated reference paper. Notably the OPV specimens exhibited consistent performance throughout the evaluated sealing temperature window. OPV B exhibited the best heat-sealability compared to OPV A and OPV C.
2. The superior grease resistance of OPV C compared to OPV A and OPV B demonstrates that an OPV can enhance paper properties and suggests that overprint varnishing can offer benefits beyond the improvement of heat-sealability.
3. These results demonstrated the potential for converting paper into a heat-sealable product using an overprint varnish. This transformation could provide print shops with the flexibility to produce diverse and valuable products from traditional coated papers and could allow paper manufacturers to produce standard products that can be further customized and converted at such print shops. The printing option also allows applying heat-seal varnish only on the sealing areas, rather than covering the entire paper, thus optimizing cost and sustainability.

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