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Programmed biodegradation capability of bio-based materials and products, validated in specific environments

MAGICBIOMAT

Manufacturing Guiding Tool for Circular and Programmed Biodegradable Materials Under Open Environment Conditions

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Acronyms

D1.4	Deliverable 1.4
D5.2	Deliverable 5.2
Fmax	Maximum tensile force
FTIR	Fourier Transform Infrared Spectroscopy
HEMA	2-Hydroxyethyl methacrylate
ISO	International Organization for Standardization
MVTR	Moisture Vapour Transmission Rate
PE	Polyethylene
RH	Relative Humidity
SCT	Short-span Compression Test
T5.2	Task 5.2
T5.4	Task 5.4
TAPPI	Technical Association of the Pulp and Paper Industry
TDS	Technical Data Sheet
T_g	Glass transition temperature
WP	Work Package

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Executive Summary

Deliverable (D)5.2 addresses the material selection and application development of biodegradable acrylic systems on paper substrates within Task 5.2. The work builds on the biodegradable acrylic systems developed and characterised in D1.4 and focuses on their implementation in paper-based structures for subsequent environmental assessment within WP5.

A kraft liner paper was selected as the substrate due to its widespread use and relevance in paper-based packaging applications. Based on the material characteristics and application requirements, one high-T_g water-based acrylic formulation developed in D1.4 was selected for direct coating, while one low-T_g water-based acrylic formulation also developed in D1.4 was selected as an adhesive layer for kraft–kraft lamination. The selected formulations were applied using a pilot-scale gravure coating process, and the resulting structures were conditioned and characterised.

The coated and laminated structures were evaluated in terms of key barrier and mechanical properties, including water absorption, oil resistance, hot oil resistance, wet tensile performance, and moisture vapour transmission. These tests were selected to assess the key functional requirements of coated kraft paper for the proposed paper-tray application. Water absorption and moisture vapour transmission were evaluated to assess moisture barrier performance, while oil resistance was used to assess resistance to liquid and heated fatty substances. Wet tensile performance was assessed to evaluate the mechanical integrity of the paper under wet conditions.

In parallel, selected high-T_g water-borne acrylic, low-T_g water-borne acrylic, and low-T_g solvent-borne acrylic polymers, together with coated and laminated kraft paper samples prepared using the high-T_g and low-T_g water-borne acrylic systems respectively, as well as PE-coated kraft paper and virgin kraft paper samples, were prepared in accordance with the requirements of the project partners.

Samples were prepared for IPC for biodegradation, ageing, disintegration, and ecotoxicity testing; for ISOTECH for real-world biodegradation studies; and for TUS for laboratory-scale biodegradation testing under freshwater and seawater conditions. Additional fresh samples will be provided to ISOTECH at a later stage for the seasonal real-world biodegradation studies under Task 5.4, which will be conducted twice, starting in winter 2026 and summer 2027, to assess the influence of seasonality under real-world conditions.

D5.2 demonstrates the feasibility of applying selected biodegradable acrylic systems to kraft paper through coating and lamination processes and provides the materials required for subsequent environmental assessment activities within WP5. The selected formulations were developed and characterised in D1.4. Detailed compositions are IP-sensitive and are therefore not disclosed in this public deliverable.

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1. Introduction

D5.2 focuses on the selection and application of bio-based biodegradable acrylic systems to develop single-use coated and laminated paper-based structures with short-term biodegradability requirements. While D1.4 focused on the synthesis, development, and characterization of biodegradable acrylic systems based on HEMA–lactide macromonomers, the present deliverable focuses on their implementation on paper substrates through representative coating and lamination processes. The high-T_g water-based acrylic system was primarily developed for the direct-coating application targeted within D5.2 (Task 5.2), while a low-T_g water-based system was additionally evaluated in a kraft–kraft laminated structure for subsequent environmental assessment. The developed paper structures were characterized in terms of their relevant barrier and mechanical properties, and representative samples were prepared for the subsequent environmental assessment activities within WP5.

1.1. Background Barrier Technologies for Paper-Based Food Packaging

The growing demand for sustainable packaging solutions has accelerated the development of renewable and recyclable paper-based alternatives to conventional plastic packaging. Driven by environmental regulations, consumer awareness, and circular economy strategies, paper-based packaging has become an important approach for reducing plastic use while maintaining the functionality required for food protection.

Despite these advantages, paper substrates generally provide limited resistance to moisture, grease, oxygen, and water vapour. These limitations restrict their use in applications requiring enhanced barrier performance. Polymeric barrier layers are therefore commonly incorporated into paper packaging structures to improve their functional properties.

A variety of barrier technologies are used in paper-based packaging, including water-based polymer coatings, solvent-based coatings, extrusion coatings, wax-based treatments, and polymer film laminations. The selection of the appropriate technology depends on the intended application, required barrier performance, processing requirements, recyclability, and cost.

Many conventional barrier systems are based on fossil-derived polymers with limited biodegradability, which can reduce the environmental benefits of paper-based substrates. Within the MAGICBIOMAT project, bio-based biodegradable acrylic polymers based on HEMA–lactide macromonomers were developed in WP1 as potential alternatives to conventional polymeric materials for paper-based packaging applications.

The biodegradable acrylic systems developed in D1.4 provide the material basis for the present work. Based on their characteristics and the requirements of the intended applications, one high-T_g water-based acrylic

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formulation was selected for direct coating, while one low-T_g water-based acrylic formulation was evaluated as an adhesive layer in a Kraft–Kraft laminated paper structure.

1.2. Objectives of D5.2

The primary objective of D5.2 is to select and apply biodegradable acrylic formulations developed in D1.4 to paper substrates and to characterise the resulting coated and laminated structures for subsequent environmental assessment within WP5. More specifically, the objectives of this work are to:

- select suitable biodegradable acrylic formulations from the systems developed in D1.4 based on their characteristics and intended applications,
- apply selected high-T_g and low-T_g water-based acrylic formulations to kraft paper through direct coating and kraft–kraft lamination, respectively;
- characterise the resulting paper-based structures in terms of relevant barrier and mechanical properties;
- prepare coated, laminated, polymer, and reference paper samples for the subsequent ageing, biodegradation, disintegration, and ecotoxicity studies within WP5.

2. Material Selection

D1.4 resulted in three families of biodegradable acrylic systems: low-T_g water-based acrylics, high-T_g water-based acrylics, and low-T_g solvent-based acrylics. For the application studies in Task 5.2, candidate formulations were considered based on their HEMA–lactide content, thermal characteristics, and the application-related performance observed during the preliminary characterisation activities reported in D1.4.

For the high-T_g water-based acrylics, formulations B, C, D, and E were investigated in D1.4. Among these systems, Formulation E, containing the highest HEMA–lactide content, exhibited favourable water resistance while maintaining improved mechanical performance compared with the benchmark formulation shown in the D1.4. Its relatively high T_g and balanced barrier and mechanical properties indicated its suitability for further evaluation as a direct coating on kraft paper.

For the low-T_g water-based acrylics, formulations L, M, and N were developed with increasing HEMA–lactide content. Formulation N, containing the highest HEMA–lactide content within this family, was selected for further application studies. The low-T_g character of this acrylic family provides the flexibility and adhesive-like behaviour required for use as an interlayer in laminated paper structures. Therefore, N was selected for evaluation in a kraft–kraft lamination configuration.

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Although a low-T_g solvent-based acrylic family was also developed in D1.4, these systems were not included in the final application sample set of Task 5.2. This selection was made considering the material availability and practical application requirements, as well as the number of samples required for the WP 5, Task 5.3 and 5.4.

Based on these considerations, Formulation E was selected for direct coating of kraft paper, while Formulation N was selected for kraft–kraft lamination. The selected formulations and their intended application routes are summarised in Table 1.

Table 1. Selected biodegradable acrylic formulations and their intended application routes.

Polymer family	Formulations developed in D1.4	Selection criterion	Selected formulation	Intended application
Low-T_g water-based acrylics	L, M, N	Low-T_g adhesive-like behaviour; highest HEMA–lactide content within the family	N	Kraft-kraft lamination
High-T_g water-based acrylics	B, C, D, E	High-T_g coating characteristics; highest HEMA–lactide content; favourable Cobb and mechanical performance	E	Paper coating

3. Application Development

3.1. Paper Substrate

Kraft paper was selected as the primary paper substrate for the coating and lamination studies. The paper used in this work was FACTURE K – Kraftliner Brown, supplied by Smurfit Kappa, with a grammage of 200 g/m^2. According to the supplier's Technical Data Sheet (TDS), the kraftliner consists of a two-layer paper structure, with the top layer composed of unbleached softwood virgin fibres and the bottom layer composed of unbleached softwood fibres combined with high-quality recycled fibres. The main technical characteristics of the selected paper, as reported in the supplier's TDS, are summarised in Table 2.

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Table 2. Characteristics of FACTURE K kraftliner brown according to the supplier's TDS.

Property	Value	Test method
Grammage	200 g/m^2	ISO 536
Moisture, typical	8.0%	ISO 287
Burst strength, typical	830 kPa	ISO 2758
Burst index, typical	4.15 kPa·m^2/g	ISO 2758
SCT cd, typical	3.80 kN/m	ISO 9895
Cobb60, top side, guaranteed	20–40 g/m^2	ISO 535

Prior to polymer application, the uncoated kraft paper was characterised using selected tests applied subsequently to the coated and laminated structures. This baseline characterisation was performed to establish a reference for evaluating the effect of the biodegradable acrylic systems on the functional performance of the paper substrate. The experimental results obtained for the uncoated kraft paper are summarised in Table 3.

Table 3. Experimental characterization of uncoated paper.

Property	Unit	Uncoated kraft paper	Test method
Cobb (1 min)	g/m^2	33	ISO 535 based
Cobb (30 min)	g/m^2	94	
3M Kit oil resistance	Kit No.	1	3M Kit Test
Coconut oil–margarine resistance	Rating	1	Internal method
Wet tensile strength (Fmax)	N	26.5	ISO 1924-2 based
Wet elongation	%	1.1	
Hot oil resistance	Rating	Poor	Internal method
MVTR (0–24 h)	g/m^2·24 h	499.2	ISO 12572 and TAPPI T 464 based

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The uncoated kraft paper was also characterised by Fourier Transform Infrared Spectroscopy (FTIR) spectroscopy to establish its initial chemical profile before polymer application. The FTIR spectra obtained from the front and back surfaces of the paper are presented in Figure 1. The spectra showed similar characteristic absorption bands on both sides, indicating comparable chemical characteristics of the two paper surfaces.

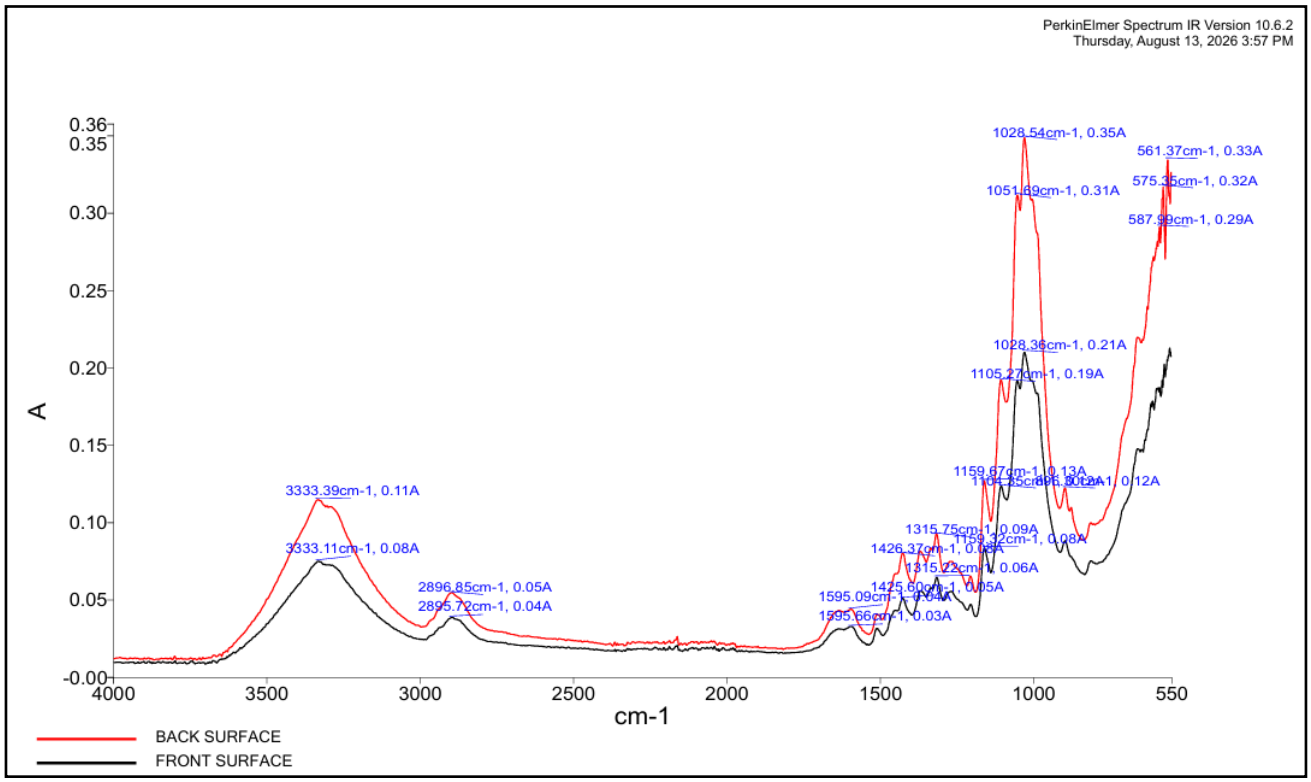

Figure 1. FTIR spectra of the front and back surfaces of the uncoated kraft paper.

3.2. Application Procedures

3.2.1. Direct Coating on Kraft

For the direct coating application, the selected high-T_g water-based acrylic system (Polymer E) was applied onto the kraft paper substrate to form a continuous polymer layer. The coating was performed using kraft paper rolls with a width of 31 cm. The selected formulation was applied at a target coating weight of approximately 14 g/m^2 using a pilot-scale gravure coating line developed and manufactured in-house by Organik Kimya (Table 4). Approximately 2 kg of Polymer E was used during the coating process.

As can be seen in Figure 2, the kraft paper was mounted as a roll on the unwinding unit of the coating line.

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Table 4. Technical specifications of the pilot- coater.

Technical Data	Parameters
Overall Length	10 mt
Oven Length	8 mt (high efficiency)
Coating Speed	Up to 100 mt/min
Coating Width	300 mm
Substrate Core Diameter	76 mm
Roll Diameter	Max 500 mm
Heating	Hot Air & Infrared (Adjustable Power)
Edge Guides	3
Tension Control Zones	5
Oven Temperature Control Zones	4
Drying Air Volume Control	0 – Max (Frequency Control)
Unwind/Rewind	Single Station
Rewind	Central & Minimum Gap

The coating formulation was introduced into the coating reservoir and transferred onto the paper surface using a gravure roller. Following application, the coated paper web was passed through a multi-stage drying tunnel. During the drying process, the coated web was exposed to infrared heating to promote water removal and accelerate film formation. The pilot-scale gravure coating process used for the application is shown in Figure 2. The drying tunnel consisted of four units, with two independently controlled drying modules in each unit. The temperature and airflow of the modules could be adjusted independently.

For the application run, the web speed was set to 25 m/min, while the drying tunnel temperature profile was set to 110, 120, 125, and 120 °C, respectively. After passing through the drying section, the coated paper was rewound into a roll for subsequent characterisation and preparation of samples for further studies.

Following coating, the coating weight was determined gravimetrically from the difference between the weights of the uncoated and coated paper samples and was found to be approximately 14 g/m^2. After completion of the coating process, the coated paper was conditioned under controlled climatic conditions at 23 ± 2 °C and 50 ± 2% relative humidity (RH) prior to sample preparation and characterisation.

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Figure 2. Pilot-scale gravure coating process used for the application of the biodegradable acrylic formulation onto kraft paper.

3.2.2. Kraft–Kraft Lamination

For the kraft–kraft lamination application, the selected low-T_g water-based acrylic system (Polymer N) was used as the adhesive layer between two kraft paper substrates. The polymer was applied onto one kraft paper surface using the same gravure coating system described for the direct-coating application. A second kraft paper substrate was then brought into contact with the coated surface to form the laminated structure. The web speed was set to 25 m/min, and the drying tunnel temperature profile was maintained at 110, 120, 125, and 120 °C, respectively. Following lamination, the samples were conditioned at 23 ± 2 °C and 50 ± 2% relative humidity (RH). The applied polymer amount was determined gravimetrically and was approximately 22 g/m^2.

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4. Characterization of Coated and Laminated Paper Structures

4.1. Cobb Test

4.1.1. Test Method

Water absorptiveness was evaluated using the Cobb method, with reference to ISO 535:2023. The test was performed on uncoated kraft paper and the direct-coated paper prepared with the high-T_g water-based acrylic system (Polymer E).

Test specimens were cut to dimensions of 13.2 × 14 cm and placed with the test surface facing upward. A Cobb ring was securely clamped onto the specimen to define a fixed test area and prevent water leakage, as shown in Figure 3. A defined volume of deionized water was then introduced into the ring and allowed to remain in contact with the paper surface for 60 s and 30 min. After the specified contact time, the water was removed and the specimen surface was gently blotted to remove excess water. The increase in specimen mass was used to determine the water absorption, expressed as g/m^2.



Figure 3. Cobb water absorption test performed on the coated and uncoated kraft paper samples.

4.1.2. Results and Discussion

The water absorption results obtained for the uncoated and direct-coated kraft paper samples are summarised in Table 5.

Table 5. Water absorption of uncoated and Polymer E-coated kraft paper determined by the Cobb method.

Sample	Cobb value, 60 s (g/m^2)	Cobb value, 30 min (g/m^2)
Uncoated kraft paper	33	94
Coated kraft paper with Polymer E	2.6	17

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The application of the Polymer E coating resulted in a substantial reduction in water absorption compared with the uncoated kraft paper. Water absorption decreased from 33 to 2.6 g/m^2 after 60 s, corresponding to a reduction of approximately 92%. After 30 min, water absorption decreased from 94 to 17 g/m^2, corresponding to an approximately 82% reduction. These results demonstrate the improved water barrier performance provided by the acrylic coating.

4.2. 3M Kit Test

4.2.1. Test Method

Oil resistance was evaluated using the 3M Kit Test, with reference to the TAPPI T 559 test method. The test was performed on the uncoated kraft paper and the direct-coated paper prepared with the high-T_g water-based acrylic system (Polymer E). The test is based on applying standard test solutions with increasing penetration strength onto the paper surface and determining the highest kit number that does not result in visible penetration or darkening of the test area. Higher kit numbers indicate higher oil resistance. The test solutions were applied as individual drops onto different areas of the paper surface and evaluated after a defined contact period. A black background was used underneath the specimens to facilitate the visual assessment of penetration.

For the present study, the oil resistance was evaluated using Kit solutions 1–12, and the highest passing kit number was recorded as the oil resistance value.



Figure 4. Visual evaluation of oil resistance using the 3M Kit Test on the paper samples.

4.2.2. Results and Discussion

The oil resistance results obtained for the uncoated and direct-coated kraft paper samples are summarised in Table 6.

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Table 6. Oil resistance of uncoated and direct-coated kraft paper determined by the 3M Kit Test.

Sample	3M Kit value	Observation
Uncoated kraft paper	1	Complete penetration
Direct-coated paper (High-T_g)	4	Partial penetration

The direct coating increased the oil resistance from Kit 1 for the uncoated kraft paper to Kit 4 for the coated paper, indicating an improvement in oil barrier performance. This enhanced grease resistance is particularly relevant to the proposed paper-tray application for oily or fatty foods, where limiting grease penetration helps maintain the integrity and functionality of the paper substrate.

4.3. Coconut Oil and Margarine Resistance

4.3.1. Test Method

Resistance to oil-containing food simulants was evaluated using a coconut oil–margarine mixture, selected based on the intended paper-tray application, as paper-based trays may meet fatty food products. The test was therefore used to assess the oil barrier performance of the coated paper samples under conditions representative of food-contact applications. The test was performed on the direct-coated and laminated kraft papers prepared with the high-T_g and low-T_g water-based acrylic systems.

50 grams of coconut oil and 50 grams of margarine were mixed and gently heated until a homogeneous liquid mixture was obtained. The mixture was then applied as individual drops onto defined areas of the paper surface. The samples were evaluated at different contact times, ranging from 15 min to 24 h. After each specified period, excess oil was removed and the reverse side and cross-section of the paper were visually inspected for oil penetration.

The oil resistance was evaluated using a qualitative scoring system, where 1 corresponds to complete penetration, 2 to partial penetration, and 3 to no penetration.



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Figure 5. Visual observation of the coconut oil–margarine resistance test at different contact times.

4.3.2. Results and Discussion

The results of the coconut oil–margarine resistance test are summarised in Table 7.

Table 7. Coconut oil–margarine resistance of uncoated and acrylic-treated kraft paper samples after 15 minutes.

Sample	Oil resistance score
Uncoated kraft paper	1
Kraft paper coated with Polymer E (High T_g)	2
Kraft paper laminated with Polymer N (Low T_g)	2

Both acrylic systems showed an improvement in oil resistance compared with the uncoated kraft paper, with the score increasing from 1 (complete penetration) to 2 (partial penetration). This indicates that the application of the biodegradable acrylic systems provided a certain degree of improvement in resistance to oil penetration, although complete oil barrier performance was not achieved.

4.4. Hot Oil Resistance

4.4.1. Test Method

Hot oil resistance was evaluated to assess the performance of the coated paper surfaces under elevated-temperature oil contact conditions. The test was performed using olive oil at 60 °C for 16 h on kraft paper coated with the high-T_g water-based acrylic system (Polymer E) and the low-T_g water-based acrylic system (Formulation N).

Three drops of olive oil were applied to different areas of the coated surface. The specimens were then placed in an oven maintained at 60 °C for 16 h. After the exposure period, excess oil was removed and both sides of the specimens were visually inspected for oil penetration, staining, or changes in appearance. The resistance was qualitatively evaluated as Good, Moderate, or Poor.

4.4.2. Results and Discussion

The results of the hot oil resistance test are summarised in Table 8.

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Table 8. Hot oil resistance of uncoated and acrylic-coated kraft paper samples.

Sample	Hot oil resistance
Uncoated kraft paper	Poor – complete penetration
Kraft paper coated with Polymer E (High-T_g)	Poor to Moderate
Kraft paper laminated with Formulation N (Low-T_g)	Poor to Moderate

Both acrylic-coated samples showed an improvement in hot oil resistance compared with the uncoated kraft paper, with the resistance classification improving from Poor to Poor-to-Moderate. However, complete resistance to hot oil was not achieved under the applied exposure conditions.

4.5. Wet Tensile Strength and Elongation at Break

4.5.1. Test Method

The mechanical performance of the paper substrate and the high-T_g water-based acrylic-coated paper was evaluated under wet conditions, with reference to ISO 1924-2. Tensile force and elongation were measured to assess the mechanical integrity of the paper substrate after water exposure.

The specimens were subjected to wet conditioning prior to testing. Tensile measurements were performed using a Zwick universal testing machine equipped with 200 N pneumatic grips. The maximum tensile force (Fmax) and elongation at break were recorded.

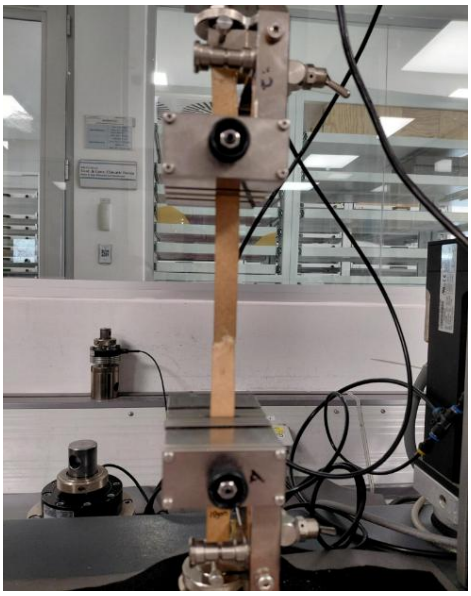

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Figure 6. Wet tensile testing of kraft paper specimens using the Zwick universal testing machine.

4.5.2. Results and Discussion

The results of the wet tensile measurements are summarised in Table 9.

Table 9. Wet tensile strength and elongation of uncoated and Polymer E-coated kraft paper.

Sample	Fmax (N)	Elongation (%)
Uncoated kraft paper	26.5	1.10
Kraft paper coated with Polymer E (High-T_g)	45.2	1.50

The Polymer E-coated paper exhibited higher maximum tensile force and elongation compared with the uncoated kraft paper. The maximum tensile force increased from 26.5 to 45.2 N, corresponding to an approximately 70.6% increase, while elongation increased from 1.10% to 1.50%, corresponding to an approximately 36.4% increase. These results indicate improved mechanical integrity of the coated paper under wet conditions.

4.6. Moisture Vapor Transmission Rate

4.6.1. Test Method

Moisture vapour transmission rate (MVTR) was evaluated to assess the moisture barrier performance of the uncoated and acrylic-coated kraft paper samples. The test method was developed with reference to ISO 12572 and TAPPI T 464. The measurements were performed by monitoring the mass change of the test assembly over time under controlled temperature and relative humidity conditions.



Figure 7. Controlled-humidity chamber used for the MVTR measurements

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4.6.2. Results and Discussion

The 24-h MVTR results of the uncoated and acrylic-coated kraft paper samples are summarised in Table 10.

Table 10. Moisture vapour transmission rate (MVTR) of uncoated and acrylic-coated kraft paper samples.

Sample	MVTR (g/m^2·24 h)
Uncoated kraft paper	499.2
Kraft paper coated with Polymer E (High-T_g)	279.5
Kraft paper laminated with Formulation N (Low-T_g)	350.8

The acrylic coatings reduced the 24-h MVTR compared with the uncoated kraft paper. Polymer E provided the higher reduction, decreasing the MVTR from 499.2 to 279.5 g/m^2·24 h, corresponding to an approximately 44% reduction. Formulation N reduced the MVTR to 350.8 g/m^2·24 h, corresponding to an approximately 30% reduction. These results indicate an improvement in moisture vapour barrier performance following acrylic coating.

5. Samples Produced for Environmental Assessment

5.1. Samples Prepared for IPC within Task 5.3 of WP5

Table 11. Samples prepared with the High-T_g acrylic system (Polymer E) within Task 5.3 of WP5

Sample	Quantity	Description	Associated test
High-T_g polymer	30 g	Polymer material only	Biodegradation
High-T_g coated paper	90 pieces (10 × 10 cm)	Kraft paper coated with Polymer E	Ageing
High-T_g coated paper	200 g (5 × 5 cm pieces)	Kraft paper coated with Polymer E	Disintegration
High-T_g coated paper	2 kg	Kraft paper coated with Polymer E	Ecotoxicity
Virgin paper substrate	200 g	Uncoated paper substrate only	Biodegradation

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Table 12. Samples prepared with the Low-T_g acrylic system (Polymer N) within Task 5.3 of WP5

Sample	Quantity	Description	Associated test
Low-T_g polymer	30 g	Polymer material only	Biodegradation
Low-T_g laminated paper	90 pieces (10 × 10 cm)	Kraft–Kraft laminated paper with Polymer N	Ageing
Low-T_g laminated paper	200 g (5 × 5 cm pieces)	Kraft–Kraft laminated paper with Polymer N	Disintegration
Low-T_g laminated paper	2 kg	Kraft–Kraft laminated paper with Polymer N	Ecotoxicity
Virgin paper substrate	200 g	Uncoated paper substrate only	Biodegradation

5.2. Samples Prepared for ISOTECH within Task 5.4 of WP5

The sample set consisted of the selected high-T_g acrylic-coated kraft paper, virgin kraft paper and PE-coated kraft paper. The latter consisted of 35 gsm PE laminated onto the same virgin kraft paper using approximately 14 gsm of a petroleum-based adhesive and will be tested as a negative control. Additional fresh samples will be supplied at a later stage for the seasonal real-world biodegradation studies, starting in winter 2026 and summer 2027. All samples were prepared in 8 cm × 8 cm dimensions, and their individual weights were recorded prior to shipment.

Table 13. Samples prepared within Task 5.4 of WP5 for short-term real-world biodegradation studies

Sample	Quantity
MAGICBIOMAT prototype – high-T_g acrylic-coated kraft paper	420
Virgin kraft paper	60
PE-coated virgin kraft paper	60
Virgin kraft paper	500 g
Kraft paper coated with Polymer E (High-T_g)	5 x 10x10 cm sheets
Kraft–kraft laminated paper with Formulation N (Low-T_g)	5 x 10x10 cm sheets

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5.3. Samples Prepared for TUS for the Extended Biodegradation Study

Table 14. Samples to be provided to TUS for biodegradation studies

Sample	Quantity
Low-T_g water-based acrylic – Formulation N	30 g
High-T_g water-based acrylic – Polymer E	30 g
Low-T_g solvent-based acrylic – Polymer_LA12	30 g

The samples were prepared within D5.2 to support the extension of the biodegradation studies previously conducted under D1.5. In D1.5, the developed materials were evaluated under freshwater and marine conditions. As an extension of this work, newly established biodegradation tests will be performed for coated paper materials, including three additional test conditions. Accordingly, TUS requested representative samples of the selected biodegradable acrylic systems, including the low-Tg water-based (Formulation N), high-T_g water-based (Polymer E), and low-T_g solvent-based (Polymer_LA12) systems, together with virgin, coated, and laminated kraft paper samples.

6. Conclusions

D5.2 demonstrated the practical application of selected bio-based biodegradable acrylic systems developed in D1.4 on a representative kraft paper substrate. A high-T_g water-based acrylic system (Polymer E) was selected for direct coating, while a low-T_g water-based acrylic system (Formulation N) was investigated as an adhesive layer for kraft–kraft lamination. The application trials confirmed that both systems could be processed using a pilot-scale gravure coating process and successfully incorporated into paper-based structures.

The direct application of Polymer E resulted in a substantial improvement in the water barrier performance of kraft paper. Cobb water absorption was reduced by approximately 92% after 60 s and 82% after 30 min compared with the uncoated substrate. The coated paper also showed improved oil resistance in the 3M Kit Test and improved resistance to coconut oil–margarine exposure. Similarly, both acrylic systems provided an improvement in hot oil resistance compared with the uncoated paper, although complete resistance to oil penetration under the applied test conditions was not achieved.

The mechanical and moisture barrier performance of the coated paper was also improved. Under wet conditions, the Polymer E-coated paper exhibited an increase in maximum tensile force and elongation compared with the uncoated kraft paper. In addition, the acrylic coatings reduced the moisture vapour transmission rate, with Polymer E providing the greatest reduction among the evaluated structures. These

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results indicate that the selected biodegradable acrylic systems can provide meaningful functional improvements to kraft paper while enabling the development of polymer-coated and laminated structures.

Alongside the application and characterisation activities, representative quantities of polymer, coated paper, laminated paper, and virgin kraft paper were prepared for the subsequent environmental assessment activities. The samples prepared for IPC, TUS, and ISOTECH will support the planned biodegradation, ageing, disintegration, ecotoxicity, and real-world degradation studies. Additional fresh samples of high-T_g coated paper and reference kraft paper will be supplied to ISOTECH at a later stage for the seasonal real-world degradation studies.

Overall, the results obtained in D5.2 confirm the feasibility of applying the selected biodegradable acrylic systems developed in D1.4 to kraft paper through representative coating and lamination processes. The developed structures provide a suitable material basis for the subsequent environmental assessment activities in WP5, while the obtained application results provide a foundation for further optimisation of barrier and mechanical performance where required.

7. References

[1] ISO 535:2023. Paper and board – Determination of water absorptiveness – Cobb method.

[2] ISO 536. Paper and board – Determination of grammage.

[3] ISO 287. Paper and board – Determination of moisture content of a lot – Oven-drying method.

[4] ISO 2758. Paper – Determination of bursting strength.

[5] ISO 9895. Paper and board – Compressive strength – Short-span test.

[6] ISO 1924-2. Paper and board – Determination of tensile properties – Part 2: Constant rate of elongation method.

[7] ISO 12572. Hygrothermal performance of building materials and products – Determination of water vapour transmission properties.

[8] TAPPI T 464. Water vapor transmission of paper and paperboard at high temperature and humidity.

[9] TAPPI T 559. Grease resistance test for paper and paperboard

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