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Influence of coating grammage on the utility properties of coated papers

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Abstract: *Influence of coating grammage on the utility properties of coated papers.*The paper coating offers the opportunity to create a product with high added value, the potential of which has been recognized by both paper mills and polygraphs.Indeed, paraffin coatings have excellent barrier, sliding and strength properties, and also increase the quality and durability of the print.
This paper presents the results of the research on the influence of the coating weight on the functional properties of the coated paper. To this end, a commercially available paper was coated with a paraffin emulsionusing various Mayer rods and then tested using standard mechanical, surface, and water absorption tests. It was found that the coating of the base paper, regardless of the amount of the applied mixture, significantly influences its hydrophobic, surface, and strength properties. Papers with the highest coating weight allowed to obtain a paper with increased strength and high surface smoothing. The completed coatings significantly increased the water barrier, regardless of their thickness

Keywords: paper coating; paper hydrophobic; paper utility properties; Mayer rod; papermaking technology

INTRODUCTION

The coating process consists of applying a coating mixture to the surface of the paper product to improve the functional properties of the paper or for other specialized applications, depending upon the type of mixture. The coating mix on the surface of paper contributes to improvement in the printability of the paper, it enables the temporary exposure of packaging papers to weather conditions or reduces the penetration of liquids and fats into packages intended for contact with food. The composition of coating mixtures may differ for various application and depends mainly on the printing technique for which the coated paper products are intended and the coating technique, and in particular the blend concentration, that can be used in a given coating technique.Depending on the intended use of the paper, it can be coated single or both sides.

In the paper industry, for the coating of cartons, ready-made packages, and cardboard, emulsions based on high-melting polyethylene waxes or ethylene homopolymers and copolymers are used.These emulsions show excellent stability, a high degree of fragmentation of the wax particles to a size below 0.5 μm [1], as well as appropriate utility parameters, consisting in the production of wax coatings with an excellent barrier, sliding, and strength properties.The produced coatings are transparent, which increases the quality and durability of the print [2,3,4].

The paraffin emulsion coatingis a certain barrier to water, as it has a much lower porosity than the substrate. In the case of printing papers, excessive liquid absorption is most often associated with poor image reproduction. Such a layer, therefore, enables a clear and defect-free print to be obtained with a much lower ink requirement than in the case of paper without such a coating. Paper-based materials produced without hydrophobising agents exhibit natural hydrophilicity, i.e. the ability to absorb water, both in liquid form and from water vapor. The rate of absorption and the amount of water that the paper can absorb in a given time depends, among others, on the ingredients of the paper and its structure, the moisture content

of the paper, the degree of water purity, or its temperature [5]. Most often, this is a disadvantageous phenomenon, because the absorption of liquid by the paper causes changes in paper dimensions (deformation) and deterioration of mechanical properties, which is important, especially for packaging papers. From the utility point of view, depending on the intended use, the coated paper should therefore have a strictly defined hydrophobicity, and thus the assessment of water absorption by the paper is one of the key methods of assessing the performance of paper.
The appearance of the coating and its thickness determine the final appearance of the paper product.Coating grammage primarily determines the functional properties of the coated paper, which undoubtedly include its hydrophobicity, but also strength properties. Therefore, this study investigated how the coating grammage influences the hydrophilicity as well as the surface and strength properties of the coated paper.

MATERIALS AND METHODS

For the tests, the commercially available Mondi ProVantage Kraftliner paper with a basis weight of 125 g/m² and the coating mixture in the form of a paraffin-water emulsion was used. Before the coating process, paper samples were cut from the rolls and subjected to air conditioning at 23°C and 50% relative humidity, according to ISO 187:1990, for a minimum of 24 hours.

The coating process was carried out with the use of Mayer rods of different numbers: 4, 5, 6, 7, 8, 9, 12, and 15, to vary the coating grammage. With the increasing number of the rod, the thickness of the coating increased. A photo of one of the rods used is shown in the drawing (Fig. 1). After the coating process, the coated paper samples were dried in a thermal research chamber (Wamed KBC-65W) at a temperature of 60°C. Thereafter, the coated paper samples were conditioned at 23°C and 50% relative humidity according to ISO 187:1990 for a minimum of 24 hours.

Figure 1. Mayer Rod

After the samples were conditioned, the following utility properties of the paper were tested:

1. Degree of hydrophobicity and/or hydrophilicity of paper, according to ISO 535:2014 (water absorption by $Cobb_{60}$ method) - Cobb apparatus (Danex, Katowice, Poland);
2. Air permeability, according to ISO 5636-3:2013 - Bendtsen apparatus (Kontech, Lodz, Poland);
3. Roughness of the coated paper surface, in accordance with ISO 8791-2:2013) –Bendtsen apparatus (Kontech, Lodz, Poland);
4. Priority strength properties of base papers, in accordance with ISO 1924-2:2010 - Zwick 005 ProLine testing machine (Zwick-Roell, Ulm, Germany), coupled with testXpert III software.

   The tensile paper properties were examined as follows:
   - I_B – breaking length [m];
   - σ_T^b – width related force with break [N/m];

- σ_T^W – force at break index [Nm/g];
- ε_T – strain at break [%];
- W_T^b – energy absorption [J/m^2];
- W_T^W – energy absorption index [J/g];
- E^b – tensile stiffness [kN/m];
- E^w – tensile stiffness index [Nm/g];
- E^* – Young's modulus [MPa];
- F_B – tensile force at break [N].

Detailed statistical analysis was performed for individual research series, determining the basic indicators - arithmetic mean, extended deviation and percentage relative error.

RESULTS AND DISCUSSION

The obtained results of the hydrophobicity of the tested samples are shown in the drawing (Fig. 2). The initial $Cobb_{60}$ water absorption value for the base paper prior to the coating process was 47 g/m². On the other hand, for the tested samples of papers coated with a paraffin mixture, Cobb's value was in the range of 0.33 ÷ 5.12 g/m² and decreased with increasing thickness of the coating applied to the base paper. Thus, applying a paraffin coating to the paper allowed to reduce water absorption by as much as 99 ÷ 89%, depending on the coating weight. Interestingly, changing the rod number by 11 units causes only a 10% difference in the water absorption value. Therefore, regardless of the number used in the Mayer rod research, coating the paper with a mixture in the form of a paraffin-water emulsion reduces the rate of water penetration into the coated substrate. Such a significantly increased hydrophobicity causes a significant increase in the usability of the paper, especially in the packaging and printing sectors.

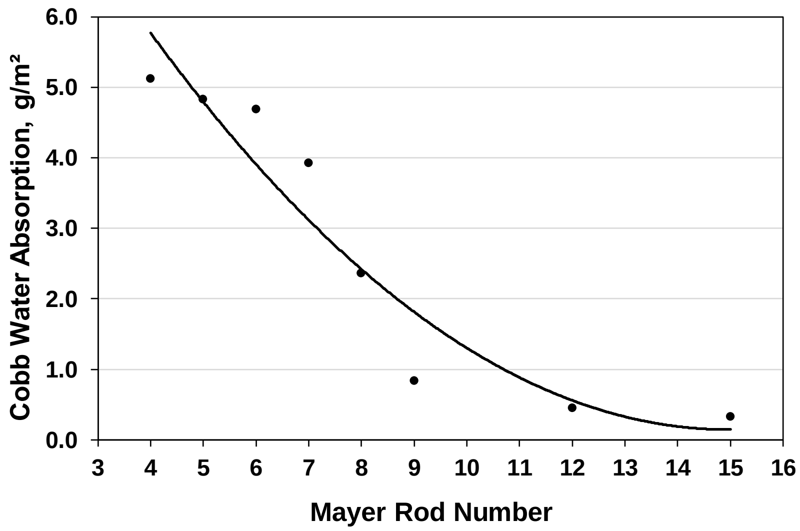

Figure 2. Influence of coating grammage on the Cobb water absorption

Printing papers should also be suitable for printing on the surface. The roughness of the paper (or its smoothness) determines the susceptibility of the surface to printing. Roughness/smoothness significantly affects also many other functional and processing values of the finished product. Table 1 shows the results obtained for the coated surface of the tested papers. The initial roughness value for the base paper before the coating process was 489 ml/min, while for the coated samples it ranged from 149 to 272 ml/min. Thus, the obtained results indicate that the increase in the thickness of the coating, as a result of using the Mayer rod with a higher number, causes the expected surface smoothing of the coated papers by 70 ÷ 44%. In the case of printing papers, this is important information, because the increase in smoothness allows you to make printing prints with a greater degree of accuracy and sharpness. The practical conclusion is that only on high-smoothness papers it is possible to accurately print an image with a high screen ruling.

Table 1. Structural properties of paper

Mayer Rod number	Roughness	Air permeability
	ml/min	ml/min
4	272 (15)	80 (7)
5	230 (21)	68 (4)
6	295 (11)	47 (4)
7	213 (16)	20 (3)
8	180 (10)	12 (4)
9	183 (13)	11 (4)
12	176 (8)	7 (2)
15	149 (11)	7 (2)

Note: Extended deviations are given in brackets.

The thickness of the coating significantly influenced another, extremely important structural property of the paper, which is air permeability. High air permeability is a desirable property in dustproof cartons and filter papers. However, many wrapping papers, and especially food packaging paper, should have a very low air permeability.

Based on the presented results, it can be observed that the coating process with the use of the coating mixture significantly influences the structure of the tested base paper. Due to the fact that air permeability depends on the porosity and density of the article structure, an increase in the thickness of the coating caused a decrease in air permeability. The starting value of the parameter for the base paper before the coating process was 202 ml/min. The coated paper samples were characterized by air permeability within the range of 7 ÷ 80 ml/min, which is as much as 97 ÷ 60% lower. Therefore, the change of the Mayer rod number by several numbers caused in this case very significant differences in the value of the considered parameter.

The level of air permeability indicates not only the porosity of the product but also other properties of the paper, including strength properties. The results of testing the strength parameters of the coated papers are presented in Table 2. It should be emphasized that the presented results were determined for the machine direction (MD). The strength parameters for this direction are of real practical value because it is in this direction that the processing processes are carried out.

Measurement of breaking length of paper is one of the most popular methods recommended for comparing the static strength properties of the tested papers. The parameter is generally used in the paper trade to describe the inherent strength of paper, and it constitutes a very good basis for comparing the strength of papers made from different materials and of different basis weight.The breaking length is a widely used indicator because it allows for estimating the usable properties of many products. This is particularly important for the evaluation of the usefulness of packaging and newsprint papers.

Figure 3 shows a comparison of the breaking length of papers with different thicknesses of the coating. The initial value of the breaking point for the base paper before the coating process was 12 650 m. Based on the presented results (Fig. 3), it can be observed that the coating process using most of the Mayer rods used (No. 4 - 9) caused a decrease in the value of the breaking length of the paper by 1 ÷ 14%. Only two samples with the highest coating weight increased the parameter value by an average of 6%. On this basis, it can be concluded that the breaking length capacity of the coated paper decreases to a certain coating thickness. Only a relatively high increase in the coating grammage causes an increase in the tear resistance properties.

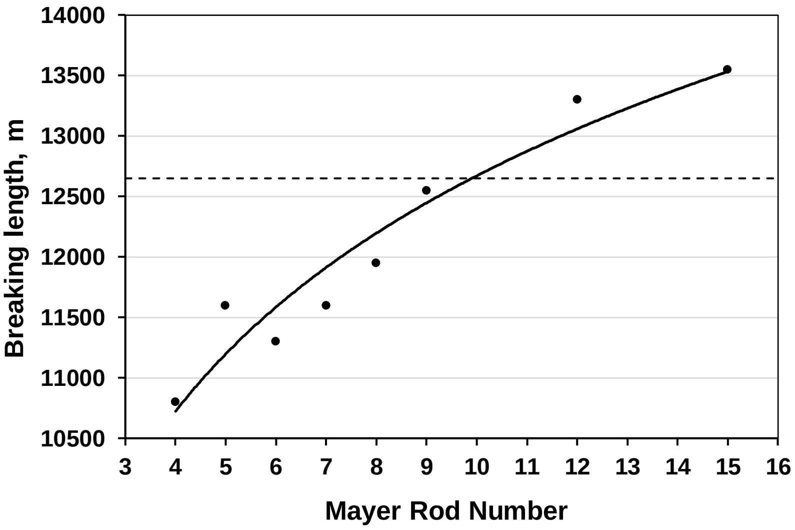

Figure 3. Influence of coating grammage on the breaking length of paper

Another analyzed index characterizing the functional properties of coated paper samples was thewidth related force with break (σ_T^b), which is one of the basic static strength properties and determines the value of the breaking load causing a 1 m wide sample of a paper to break.

The value of the σ_T^b for the base paper before the coating process was 15 490 N/m, while after coating it was within the range of 13 700 ÷ 18 570 N/m. Interestingly, applying the coating with some Mayer rods resulted in a decrease in the parameter by 4 ÷ 12% (rods No. 4 - 7), or its increase to 20% (rods No. 8 - 15). Regardless of that, the increase in the coating grammage caused a commensurate increase in the width related force with break(Tab. 2).

The force at break index (σ_T^W) was also determined, i.e. the value of the width related force with break that a hypothetical 1 g/m² paper sample would achieve. The force at break index is therefore an extremely practical parameter, because it allows a free and reliable comparison of coated paper samples, both for a wide range of base papers of different weights and for paper with coatings of different weights. Therefore, the presented property allows the coated sample of the paper to be assessed in terms of its material properties.

The base paper used for the coating process had an initial value of the force at break index at the level of 123.8 N/mg, while the coated samples were 105.9 ÷ 133.2 N/mg. Thus, depending on the grammage of the coating, an increase or decrease of the considered parameter was observed (Tab. 2).

The same characteristics of the test specimen as the width related force with break represent thetensile force at break (F_B). This parameter is also one of the basic static properties that characterize the performance of paper products. It specifies the limit value of the stress which, if exceeded, will break the tested sample of the coated paper. As in the case of breaking length, this property is important as it has a decisive influence on the behavior of the paper web during its high-speed processing (e.g. during the coating process on individual sections of the coater). A desirable feature for coated paper is the tensile force at break parameter as high as possible. The lower the value of the paper tensile force at break, the greater the probability of a break during the operation of a drying process or a coated web winding operation.

The uncoated backing paper had an initial tensile force at breakof 155.6 N. This parameter for the coated samples was in the range of 136.4 ÷ 183.0 N. Similarly to thewidth related force with break, the coatings applied with some Mayer rods caused a decrease in the tensile force at breakof the paper to 12% (rods no. 4 - 7) or an increase of the parameter value by 3 ÷ 18% (rods no. 8 - 15) (Tab. 2).

Strain at break of paper (ε_T), defined as a measure of deformation under tensile stress, up to the point where the paper sample breaks, significantly affects the behaviour of coated paper under production conditions paper.

The initial strain at breakfor the base paper prior to the coating process was 2.53%. Coating the samples, regardless of the thickness of the applied coating, increased the stretchability of the paper by 6 ÷ 14% (Tab. 2).

The consensus between tensile force at break and strain at break is the energy absorption parameter (W_T^b). The energy absorption describes the resistance of the test paper to the dynamic load acting on it. The higher the values of the energy absorption the tested paper achieves, the more resistant it is to the dynamic loads acting on it.

The initial value of the energy absorption for the base paper before the coating process was 245.4 J/m². Based on the obtained results, it can be observed that only the use of the lowest number rod resulted in a slight decrease in the parameter. The remaining samples, coated with rods no. 5 - 15, were characterized by higher values of the energy absorption by 2 ÷ 31% (Tab. 2). An increase in the value of the energy absorption with the increase of the coating grammage was also observed.

Taking into account different weights of coatings, the analysis of the energy absorption of the samples was extended to include the energy absorption index, i.e. the work necessary to break the tested paper sample with respect to its weight. The initial value of the considered parameter for the base paper before the coating process was 1.96 J/g. The analysis of the results showed an increase in the energy absorption index for the samples with the highest grammage of the coating by 9 ÷ 22%. Samples with lower coating thicknesses (coated with rods no. 4 - 8) showed a decrease of the considered parameter not exceeding 9% (Tab. 2).

For the analyzed samples, the tensile stiffness, i.e. the resistance of the paper samples to deformations caused by external tensile forces, was also determined. The initial value of the tensile stiffness for the base paper was 1,290 kN/m, while for the coated samples it was within the range of 1,098 ÷ 1,438 kN/m (Tab. 2). Depending on the Mayer rod used, the application of the coating compound to the paper resulted in a decrease or increase in the parameter value. It was also observed that with the increase of the coating grammage, the tensile stiffness of the sample increased.

In the case of the tensile stiffness index, a decrease in the parameter was observed for most of the tested samples by 6 ÷ 18%. Only for the papers with the highest grammage of the coating, coated with rods no. 12 and 15, a very slight increase in the value of the considered parameter was observed (Tab. 2).

The last parameter tested for papers coated with various mixtures was Young's modulus of elasticity. This parameter characterizes the ability to distribute stresses acting on the material and describes the ability of an elastic body to resist deformation when stretched. The lower the value of Young's modulus, the better the tested paper has the ability to distribute stresses acting on it.

The base paper used for the tests was characterized by the initial value of Young's modulus at the level of 11,650 MPa. The coating of the paper caused an increase or decrease in the value of the considered parameter, depending on the grammage of the coating. The use of rods with numbers 4 - 7 contributed to a decrease in Young's modulus by 7 ÷ 14%. On the other hand, for rods 8 - 15, an increase in the parameter by 2 ÷ 12% was observed. Importantly, the increase in the coating grammage caused a proportional increase in Young's modulus (Tab. 2).

Table 2. Tensile properties of paper

Mayer Rod number	σ_T^b	σ_T^W	F_B	ε_T	W_T^b	W_T^W	E^b	E^W	E^*
	N/m	Nm/g	N	%	J/m^2	J/g	kN/m	Nm/g	MPa
4	13700 (380)	105,9 (3,0)	136,4 (4,9)	2,76 (0,17)	232,0 (20,4)	1,79 (0,16)	1098 (26)	8487 (194)	9990 (237)
5	14870 (445)	113,8 (3,4)	145,4 (4,7)	2,75 (0,12)	249,7 (19,1)	1,91 (0,15)	1187 (15)	9056 (99)	10790 (137)
6	14840 (320)	110,5 (2,5)	145,6 (2,8)	2,77 (0,11)	250,4 (16,3)	1,87 (0,12)	1145 (25)	8545 (173)	10420 (230)
7	14870 (445)	113,8 (3,4)	145,4 (4,7)	2,75 (0,12)	249,7 (19,1)	1,91 (0,15)	1187 (15)	9056 (99)	10790 (137)
8	16250 (519)	117,4 (3,7)	159,6 (4,8)	2,68 (0,10)	261,6 (17,3)	1,91 (0,12)	1303 (29)	9499 (216)	11850 (276)
9	16960 (366)	123,2 (2,8)	166,5 (5,4)	2,78 (0,11)	293,5 (18,1)	2,13 (0,13)	1339 (31)	9729 (228)	12170 (291)
12	17520 (368)	130,3 (2,8)	172,1 (4,7)	2,89 (0,09)	322,6 (19,6)	2,40 (0,15)	1394 (26)	10360 (217)	12650 (237)
15	18570 (492)	133,2 (3,3)	183,0 (6,3)	2,83 (0,15)	321,4 (25,4)	2,31 (0,18)	1438 (61)	10316 (424)	13070 (546)

Note: Extended deviation are given in brackets.

CONCLUSIONS

Based on the conducted research, it was found that the basic functional properties of paper depend on the pigment-adhesive mixture applied as a coating on the paper. The characteristics of the Cobb water absorption curve, as well as the results of tensile and structural parameters, indicate that the highest hydrophobicity, surface smoothing, and highest mechanical properties are achieved in papers with the highest coating weight. Interestingly, not all coatings increase the tensile parameters of the paper. The decrease in strength was observed for samples with the thinnest coatings, which may be caused by the uneven distribution of the mixture on the surface, resulting in local weaknesses in the paper structure. The test results, therefore, suggest that the most effective migration of binding agents takes place in the thickest coatings. This leads to a homogeneous distribution of the binders in the dry film. Thus, not only increasing the number of coating agents but also controlling the uniformity of the formed coating structure is decisive in improving the performance of coated papers.

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Streszczenie: *Wpływ gramatury powłoki na właściwości użytkowe papierów powlekanych*. Powlekanie papieru daje możliwość stworzenia produktu o wysokiej wartości dodanej, którego potencjał dostrzegli zarówno papiernicy, jak i poligrafowie. Powłoki parafinowe posiadają bowiem doskonałe właściwości barierowe, poślizgowe i wytrzymałościowe, a także zwiększają jakość i trwałość druku.

W niniejszej pracy przedstawiono wyniki badań wpływu gramatury powłoki na właściwości użytkowe powleczonego papieru. W tym celu komercyjnie dostępny papier został powleczony emulsją parafinową, przy użyciu różnych prętów Mayera, a następnie przebadany przy użyciu standardowych testów mechanicznych, powierzchniowych i absorpcji wody. Stwierdzono, że powleczenie papieru bazowego, niezależnie od ilości nałożonej mieszanki, istotnie wpływa na jego właściwości hydrofobowe, powierzchniowe i wytrzymałościowe. Papiery o najwyższej gramaturze powłoki pozwoliły uzyskać papier o zwiększonej wytrzymałości i wysokim wygładzeniu powierzchni. Wykonane powłoki znacznie zwiększyły także barierowość względem wody, niezależnie od ich grubości.

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