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Research Article

Surface Microgeometry and Digital Print Performance of Biopolymer Modified Composite Paper

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ABSTRACT

We evaluate the surface microgeometry and digital print performance of composite papers containing cotton cellulose, modified polyacrylonitrile fibres and collagen hydrolysate recovered from leather waste. We compare the reported profilometric measurements and printed layer thicknesses of six paper samples. The arithmetic mean profile deviation, Ra, ranges from 3.201 to 4.040 μm , while Rz ranges from 18.302 to 19.521 μm . Sample 2 has the lowest reported Ra and Rz values. Printed layer thicknesses range from 1.36 to 1.50 μm and do not rank the samples in the same order as surface roughness. We also identify an internal inconsistency: four reported Rq values are lower than their corresponding Ra values, which requires verification against the original profiles. We therefore distinguish descriptive differences between samples from demonstrated printing advantages. Our analysis supports a combined assessment of surface topography, colour reproduction and process conditions rather than selection based on a single roughness parameter.

KEYWORDS

Composite paper, collagen hydrolysate, surface microgeometry, profilometry, surface roughness, digital printing, toner layer, colour measurement.

INTRODUCTION

When we assess paper made with secondary raw materials, mechanical strength alone does not establish its suitability for printing. We also need to examine the surface that receives the image. Local irregularities can affect contact with the printing system and the uniformity of the deposited image layer. We therefore consider surface measurements alongside the properties of the printed sheet [1, 4, 5].

Collagen hydrolysate recovered from leather waste offers a potential route for incorporating a secondary protein component into paper. Reviews of leather waste utilisation describe routes for recovering useful materials, including protein products [2, 3]. However, we cannot infer satisfactory print performance from waste recovery alone. The resulting paper must be assessed for its intended process and application.

In this study, we examine six composite paper samples using the available surface and printed layer data. We aim to identify differences between the samples, check the internal consistency of the reported measurements and establish the limits of the resulting printing recommendations. We present a comparative analysis of existing laboratory results; we do not report a new experimental campaign.

LITERATURE REVIEW

We use the printing system as the context for interpreting paper properties. The handbook edited by Kipphan covers printing technologies and production methods [4], while the handbook edited by Holik addresses paper manufacture and subsequent processing [5]. These references provide the technological context for our analysis. They do not establish a universal roughness

threshold for the particular composite papers considered here.

Hubbe reviews bonding between cellulosic fibres and the contribution of dry-strength agents [6]. We draw on this work to distinguish internal fibre bonding from surface topography. An additive may influence the structure of a sheet without producing an equivalent improvement in every surface parameter. Accordingly, we treat stronger bonding and a smoother printing surface as separate outcomes that require separate evidence.

We also distinguish profile measurements from areal surface measurements. ISO 21920-2 specifies terms and parameters for profile surface texture, whereas ISO 25178-2 addresses areal surface texture [11, 12]. A line profile describes only the sampled path. We therefore avoid treating its Ra value as a complete description of the entire sheet. Measurement direction and sampling position remain relevant when we compare fibrous materials.

For paper and board, ISO 8791-4 describes the Print-surf air leak method [7]. We regard this as a complementary approach rather than a direct substitute for stylus or optical profile measurements. Results obtained by different measurement principles should not be equated solely because they are expressed as roughness. A comparison would require measurements on the same specimens under documented conditions.

For printed images, ISO 13655 addresses spectral measurement and colourimetric computation [8]. We distinguish this measurement framework from process-specific production requirements. ISO 12647-2 concerns offset lithographic processes [9], while ISO 12647-8 addresses

validation print processes working directly from digital data [13]. We therefore do not interpret a comparison with an offset reference as sufficient proof of compliance for a digital printing process.

These sources lead us to a sequential assessment. First, we check whether the surface parameters are internally consistent and comparable. Next, we assess the printed image under a defined process condition. We use this distinction throughout the present analysis so that numerical differences between samples are not confused with verified improvements in print quality.

METHODS

We analyse the six-sample dataset reported in Tables 3.11 and 4.1 of the underlying research [1]. The first table provides R_a , R_z and R_q ; the second provides values described as printed layer thickness. We retain the original sample numbers

$$R_a = (1/n) \times \sum |z_i|; \quad R_q = \sqrt{[(1/n) \times \sum z_i^2]} \quad (1)$$

Here, z_i is the profile height relative to the mean line and n is the number of evaluated points. For the same processed profile and evaluation length, these definitions imply $R_q \geq R_a$. We apply this inequality as an internal consistency check. We do not reconstruct R_z from the available numbers because its calculation must be linked to the specified standard and the instrument settings.

We calculate a relative difference as $\Delta = [(a - b)/a] \times 100\%$, where a is the reference value and b is the compared value. We calculate the arithmetic mean across the six samples as $\bar{x} = \sum x_i / 6$. This mean describes the set of formulations; it is not a mean of repeated measurements on one specimen. We consequently do not use it to estimate

from 1 to 6. We do not assign a collagen hydrolysate dosage to each number because the correspondence between these tables and the formulation series requires separate confirmation.

The investigated material system contains cotton cellulose, modified polyacrylonitrile fibres and collagen hydrolysate. The research record identifies a Konica Minolta C4065 digital press and reports a room temperature of 23 °C and relative humidity of 50%. We use these as documented experimental conditions. We do not infer full conformity with a conditioning standard from temperature and humidity alone; the conditioning history and monitoring procedure must also be recorded [10].

For a discretely sampled profile, we express arithmetic mean deviation and root mean square deviation as follows [11]:

measurement repeatability or instrument precision.

We perform no significance testing because individual profiles and replicate measurements are unavailable. We also avoid fitting a causal regression to six sample-level values with incompletely specified formulation matching. For future controlled comparisons, we would document thickness and density alongside surface measurements, using the relevant measurement framework in ISO 534 [14].

We retain the reported layer thickness values without presenting them as independently verified measurements. The description of the direct thickness measurement procedure needs



clarification before we can use these values for a coating mass balance or a claim about toner transfer efficiency. Our numerical analysis is therefore descriptive and limited to the reported dataset.

RESULTS

Table 1. Surface parameters and reported printed layer thicknesses

Sample	Ra, μm	Rz, μm	Rq, μm	Layer, μm
1	4.040	19.421	3.021	1.36
2	3.201	18.302	3.020	1.41
3	3.312	19.031	3.262	1.46
4	3.332	18.340	3.309	1.47
5	3.234	18.500	3.453	1.50
6	3.232	19.521	3.847	1.49

Across the six samples, we obtain a mean Ra of $3.392 \mu\text{m}$ and a mean Rz of $18.853 \mu\text{m}$. Rz spans $18.302\text{--}19.521 \mu\text{m}$. Sample 6 combines a relatively low Ra of $3.232 \mu\text{m}$ with the highest Rz. We therefore cannot assume that a lower arithmetic mean deviation also indicates a lower value of every height-related parameter. Our consistency check identifies $R_q < R_a$ in Samples 1–4. The largest discrepancy occurs in Sample 1, where Ra is $4.040 \mu\text{m}$ and Rq is $3.021 \mu\text{m}$. These values cannot represent the two standard quantities calculated from exactly the same processed profile. Possible explanations include transcription errors, different profile filters or different evaluation lengths. We cannot determine the cause without the original measurement files.

The reported printed layer thickness ranges from 1.36 to $1.50 \mu\text{m}$, with a six-sample mean of 1.448

We summarise the surface parameters and reported printed layer thicknesses in Table 1. Sample 2 has the lowest Ra, at $3.201 \mu\text{m}$, while Sample 1 has the highest, at $4.040 \mu\text{m}$. The difference is $0.839 \mu\text{m}$, equivalent to 20.8% of the Sample 1 value. We interpret this as a descriptive difference rather than a statistically demonstrated treatment effect.

μm . Sample 5 has the highest value, whereas Sample 2 has the lowest Ra and Rz. Thus, we observe no common ranking across all the reported quantities. A thicker deposited layer is not, by itself, evidence of a more uniform image or better colour reproduction. We do not use these results to establish a collagen dosage optimum. The dataset supports comparison of numbered specimens but does not isolate the independent effects of additive concentration, fibre composition or processing conditions. We would need a controlled formulation series to separate those contributions.

DISCUSSION

We interpret surface roughness as one component of print performance. Similar Ra values can coexist with different profile height

characteristics, as shown by Samples 2 and 6. For this reason, we would combine several surface descriptors with image measurements rather than select paper using Ra alone. If areal topography is measured, we would report the corresponding areal parameters separately from profile parameters [11, 12].

We consider the distribution of collagen hydrolysate within the fibrous structure a plausible influence on surface behaviour. However, the available data do not isolate this mechanism. We therefore do not claim that the additive reduced roughness by a particular percentage. To test that proposition, we would hold fibre composition, sheet formation, drying and calendering conditions constant while varying only the additive dosage [1, 6].

We also distinguish toner-based digital printing from the penetration and setting of liquid offset ink. Their interactions with paper cannot be assumed to be identical [4]. We consequently avoid describing the reported 1.36–1.50 μm interval as universally optimal. We would assess layer uniformity, adhesion and image continuity under the actual printing process before recommending a production setting. For a further validation programme, we would use a common test file and document paper orientation, conditioning history and press settings. We would combine profile measurements with a paper-specific air leak test and spectral measurements under defined conditions [7, 8, 10]. Where the intended output is a validation print, we would assess the applicable requirements of ISO 12647-8 [13]. This would connect the measurement procedure to the intended product.

CONCLUSION

We find that the six composite papers differ in their reported surface profiles, with Ra ranging from 3.201 to 4.040 μm and Rz from 18.302 to 19.521 μm . Sample 2 records the lowest values for both parameters. We do not interpret this finding as proof that it provides the best overall digital print performance. We identify four Rq values that require verification against the original profiles. We also find that the reported layer thicknesses do not rank the specimens in the same order as surface roughness. We therefore recommend a combined assessment based on documented profilometry, controlled printing and colour measurements. This approach would allow us to develop better-supported recommendations for biopolymer modified composite paper.

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