COST EFFICIENCY WITH IMPROVED COATING COLOR STABILITY – ENABLING REDUCED BINDER USAGE

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SUMMARY

In today's economic climate, the primary requirement in the paper and board industry is cost efficiency. The industry is continuously optimizing the addition levels of the coating color components without sacrificing the runnability or the end product quality.

In this study we have compared coating colors with varying stability. We have further developed laboratory methods to simulate the coating process and to measure the coating color stability. We have monitored the changes in coating color composition by analyzing the particle size distribution and the ratio of organic and inorganic material. We have shown that good coating color stability leads to a more uniform coating color in machine, and also allows the cost reduction by enabling the optimization of the coating color components. Additionally, this will minimize the changes, i.e. improve stability (particle size distribution, solids, viscosity, latex level) of the coating color in the recirculation. In reality there does not exist a process where the coating color composition in the circulation is the same as it is in make-down.

By maintaining the coating color composition constant the coating color in the circulation more closely resembles the fresh coating for longer periods of time, thus reducing the fluctuation of the quality in the machine direction. Good coating color stability in the circulation enables paper and board producers to get cost savings due to more stable runnability, improved end product quality and optimized use of coating color components.

INTRODUCTION

The paper industry has sought cost savings during the past years through using lower cost raw materials and optimizing the dosages. Typically, the focus has been in minimizing the total cost of binders and co-binders. This optimization is limited by the paper strength needed in the printing process.

When developing formulations the pigments, binders and their characteristics are the center of attention, but less attention has been paid to control binder distribution in the z-direction and the porosity in a coated layer. Both cost reduction and quality improvement can be achieved by controlling the z-directional binder distribution. This is especially important at lower binder levels.

Binder distribution in a coated layer

There are driving forces, such as the pressure penetration, the capillary absorption and the heat, which causes material movement in the z-direction in a coating process. On the other hand there are parameters in the coating colors which either allow or restrict the movement of particles relatively to each others.

It has been shown that the latex binder can move relative to the pigments only when the pigments are larger compared to the latex size, and this is not influenced by the binder level(1). To allow relative movement the pore size between pigments must be larger than the latex size. Thus, also the pigment particle size distribution is of importance – there is more latex movement towards the base paper with narrow particle size distribution pigments than in the coatings containing pigments with a broad particle size distribution. Also, the particle size distribution has been proposed to be more important than particle aspect ratio in terms of the latex mobility (2). In accordance with earlier discoveries about the pigment size and size distribution is the sort that a latex with a small particle size is reported to have a higher tendency to migrate than a latex with a large particle size (3,4).

Water functions as a carrier for solids particles. A natural direction of the material movement is towards the base web during the pressure penetration (during the coating application and under the metering element), and during capillary absorption (between the application and the metering element). There are many studies in the literature(5,6,7) about the effect of the drying conditions on binder migration and many discrepancies between the conclusions. It has been proposed that drying, in fact, would stop the binder movement rather than cause it (6), and also the boundary theory

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was used to explain binder rich surfaces(7). Based on several studies, the movement of both the binder and the water would be always towards the substrate.

Controlling parameters for binder movement in z-direction

There is a lot of literature about controlling binder migration and penetration. The following factors, among others, have been found to affect the migration:

- The type of base paper (8)
- High coat weight, low solids content and low density of the filter cake (9,10)
- The web temperature(11)

Additives which can contribute to the interactions between the pigment and the binder can reduce the latex mobility (12). Polymer co-binders have been found to influence binder migration (1,13-16). They were found to prevent both the binder migration and the penetration. The ionic polymers in character, such as carboxymethyl cellulose (CMC), are stated to form a three-dimensional network in the coating color which effectively prevents the migration of latex particles to the coating layer surface. It has been assumed that an improved latex retention was due to the increased continuous phase viscosity with the help of CMC (15,17). CMC would not only reduce the migration of latex binder towards the base sheet prior to the coating immobilization, but also the pigment fines. It has also been suggested (15,17) that an even distribution of the particles prior to the immobilization point gives a better film forming in the pigment matrix. It has also been found that coating colors containing CMC had a higher latex content and better uniformity than those without CMC (18).

A new way to optimize a coating color

The mechanism of the solids increase in the circulation, which is induced by the dewatering, is well understood. Between the application and the metering blade the dewatering causes a filter cake formation, and it has been assumed (19,20) that there is a distinct drop in the solids content between the filter cake and the liquid coating color. However, compared to the amount of literature about the dewatering, it is less well known that the coating color solid particle fractions change in the coating color circulation. This successfully proves that there is no difference in the solids content between the filter cake and the liquid coating color. The share

of the coarse fraction increases and the share of the fine fraction decreases with time. Typically, a fine particle size fraction consists of latex binder and fine pigments. The change affects the coating color stability in function of time, as well as the real binder level in the system. In reality there does not exist a process where the coating color composition in the circulation is the same as it is in make-down. Significant cost savings can be achieved when coating color stability is improved. This improved stability will allow lower binder amount while maintaining the surface strength.

There are only few studies in the literature where time dependent changes in the solid particle fractions have been studied. McKenzie *et al.,* (21) and Luchtenberg *et al.,* (22) presented a laboratory method and control mechanisms for the particle size segregation. As a mechanism for particle size segregation, it has been proposed that the small particles concentrated near boundaries can push the large particles outward, and therefore large particles would be selectively metered away from the web (23). Another proposed mechanism is the pulse dewatering (24). As large particles get left behind because of their inertia, they are separated from the liquid phase and from small particles near the stagnation streamline due to the pulse dewatering.

The purpose of this paper is to show how the coating color stability can be measured with relatively simple methods in the laboratory scale, and what are the consequences of binder and fine pigment fraction depletion for the coating color stability, the paper quality and the formulation cost.

MATERIALS AND METHODS

The coating colors consisted of fine calcium carbonate and fine clay and styrene-butadiene latex binder. The used co-binders were conventional or modified carboxymethyl cellulose (CMC). The optical brightener was used in all coating colors. The coating color formulations are presented in Table I, and trade names are listed in Appendix 1. The coating colors were adjusted to the dry solids content 63 wt-% and pH 8.5. The co-binder levels were adjusted so that both coating colors had comparable runnability. This was evaluated by capillary viscosity at 800 000 1/s (actual level 40±5 mPas, 25ºC).

The coatings were carried out with the laboratory scale coater (DT Paper Science) for the uncoated base web (description in Appendix 1). The coater speed was 70 m/min, the roll applicator unit was used in the application and a blade with a stiff mode

Table 1. Coating color formulations

COMPONENTS, pph	#1	#2
Fine calcium carbonate	70	70
Fine clay	30	30
Conventional CMC	0.5	
Modified CMC		0.7
Latex	10	10
Optical brightener	0.5	0.5

Table 2. The share of different fractions for the raw materials as volume percentages: fine <0.8 μm and coarse >0.8 μm

Size fraction,%	Fine	Coarse
Latex	100	0
Fine calcium carbonate	69	31
Fine clay	100	0

Table 3. Coating color analysis results

	#1	#2
Solids content, %	63.1	63.1
Brookfield-viscosity (100 rpm),mPas	700	1250
Capillary viscosity (800 000 1/s), mPas	37	43
Water retention, ÅA-GWR, g/m²	140	105
Water retention, Novicoater, delta-%	2.7	1.3
Ash content of color before coating, %	87.3	87.5
Ash content of color after coating, delta-%	1.1	0.7

was used to adjust the coat weight 9-10 g/m². The coated side of the web was dried with infrared and air dryers. The water retention of the coating colors (CP Kelco, Novicoater method), particle segregation tendency and binder depletion can be evaluated by the method. The detailed description for the method has been presented by McKenzie *et al.,* (21).

The particle size distributions of raw materials, make-down and circulated coating colors were measured with a Beckman Coulter Counter LS 13 320 laser diffraction instrument. The particle size distributions were evaluated by dividing distributions into the two fractions described in **Table 2**. The fractions are fine (latex + fine fractions of pigments: <0.8 μm) and coarse (pigments: >0.8 μm). This division was based on the particles size distribution of the fine

clay, which has 100% of the particles smaller than 0.8 μm.

Surface strength was evaluated according to standard ISO 3783:2006. Other used test methods are presented in Appendix 2.

RESULTS AND DISCUSSIONS

The coating color characteristics are presented in **Table 3**. The **Figures 1-2** and **Table 4** summarize the results for the changes in the particle size distributions of the coating colors in the coating circulation in function of the time.

There were changes in particle size distributions of the coating colors during coating circulation. Figures 1 and 2 show a relative decrease in fine particle size fractions and a relative increase in the coarse particle size fractions for the circulated coating colors.
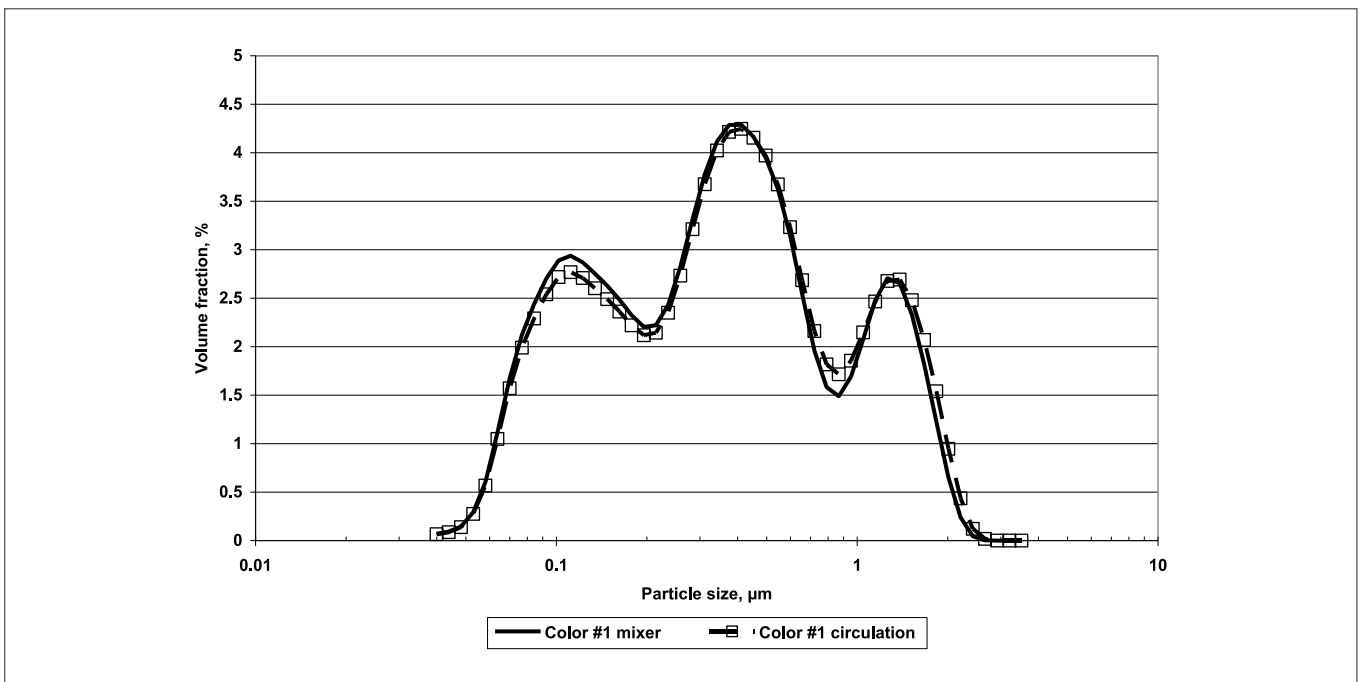

Figure 1. Particle size distributions of coating color #1 from a mixer and after the coating process circulation
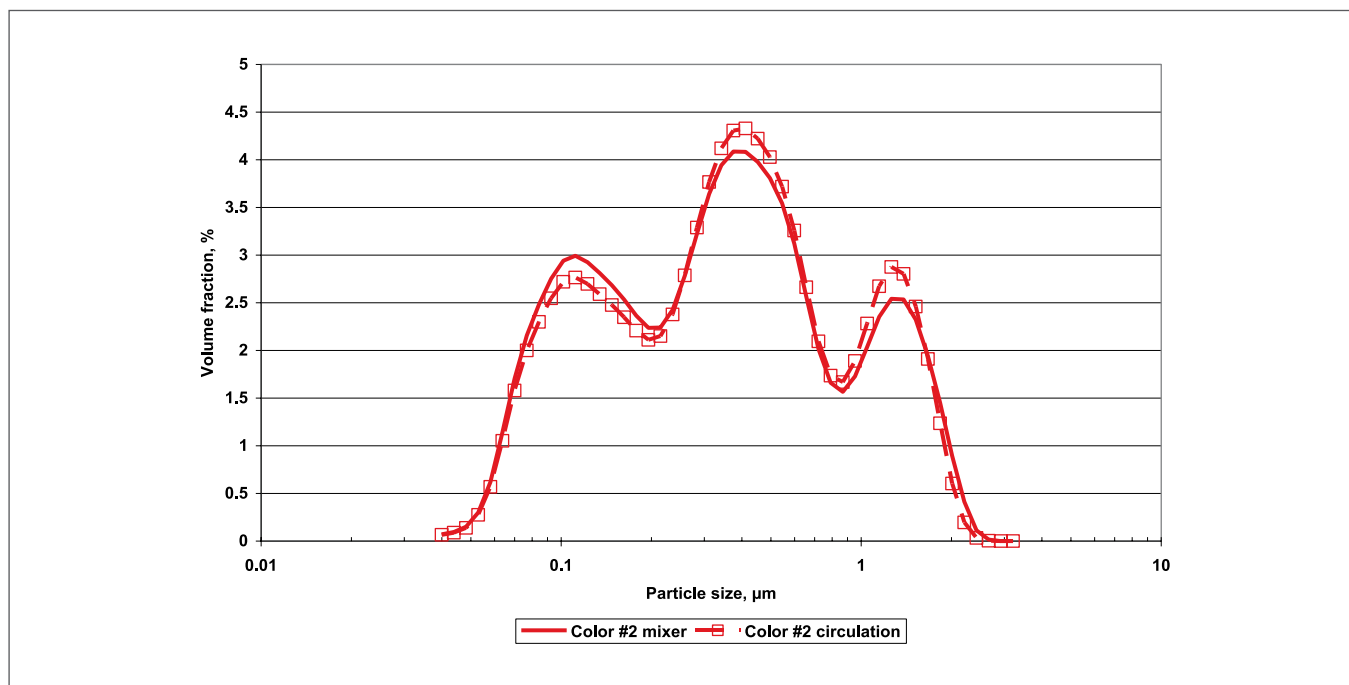
Figure 2. Particle size distributions of coating color #2 from a mixer and after the coating process circulation

As the changes are difficult to evaluate accurately from the above presented figures, the changes in particle size distributions were evaluated by calculating the changes of the each fraction as described in the Materials and Methods section. The changes are shown in **Table 4**.

Table 2 shows that the fine fraction consisted of latex and fine pigments, coarse fraction consisted only of pigments. Table 4 shows that there were changes in the particle size distributions of the tested coating colors. The fine particle size fraction was prone for the depletion, which is in accordance with other studies (21,22,24,25). The coating color #1 depleted more than the coating color #2. In both cases the coarse particle size fractions increased relative to fine particle size fractions – the coating color #1 changed more than the coating color #2.

The inorganic/organic ratio measured as ash contents increased for both type of coatings, supporting the interpretation of the depletion of the organic material. The inorganic/organic ratio measurements showed that the depletion of the binder was real and not caused, for example, by the shear induced aggregation mentioned in the literature (26). The changes of ash contents were higher for the coating color #1 than for the coating color #2.

There is a stability point in the changes in the coating color based on the mass balance between used amount make-down and circulated color (22). The laboratory study did not show the stability point, but the speed of changes can be evaluated by the presented method. The larger change in the short laboratory run predicts large changes before the stability point is achieved. High size segregation tendency in the beginning of a coating accelerates all changes in the coating color. During a mill-scale run, a make down coating color is mixed with the circulated coating color and particle size differences even increase and, thus, also size segregation tendency increases. We have found a good correlation between the laboratory coatings and full scale coatings in the rate of the depletion tendency, which describes the stability of coating colors and potential to optimize binder dosages.

The reference colors were used to develop a calibration curve for the binder – delta ash content relationship (shown in Appendix 2). Based on the calibration curve, it could be estimated that the binder amount depleted from the coating color #1 was 2 pph, and for the coating color #2 it was 1 pph. If one takes a coating color #1 as a reference and make an assumption that the reached binder amount of 8 pph in the circulation would be a stability point. With

Table 4. Changes of particle size fractions during the coating process circulation

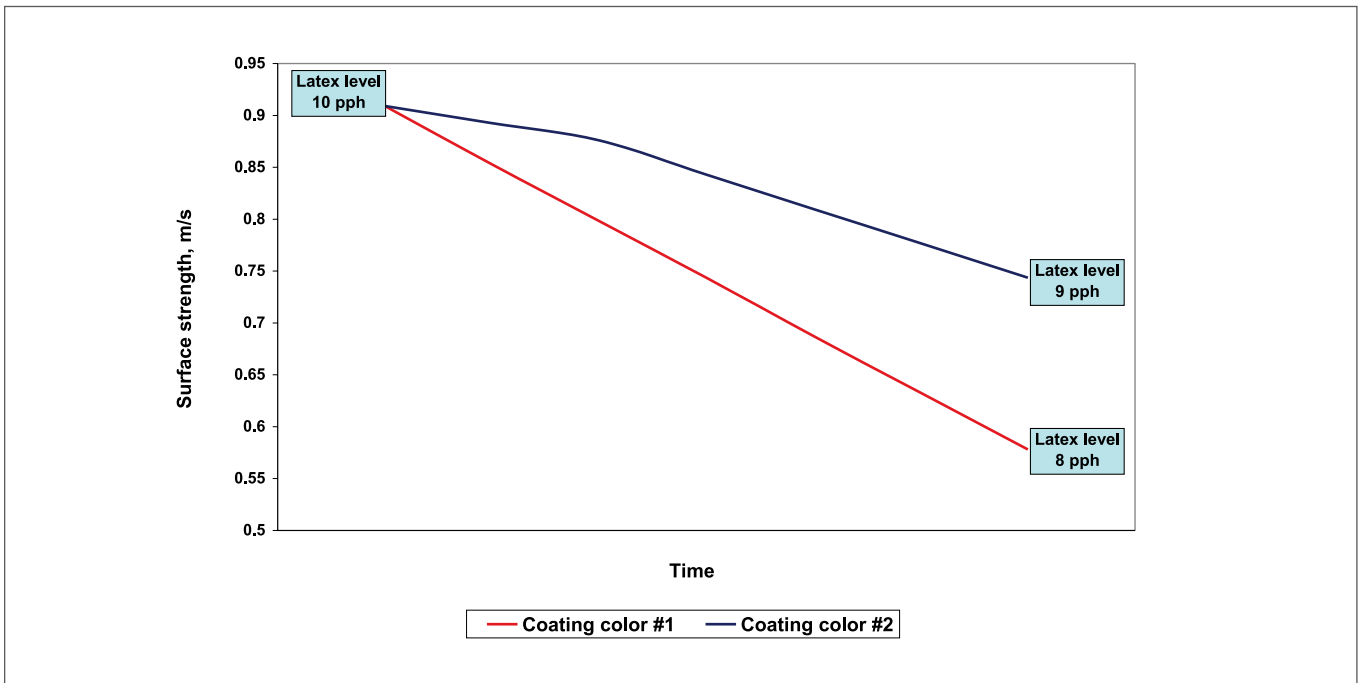| Volume change, %	Fine	Coarse
Color #1	-1.75	1.75
Color #2	-0.72	0.72

Figure 3. Surface strength in function of time

coating color #2, with lesser depletion tendency, the binder level could be decreased from 10 pph to level 9 pph and still maintaining corresponding paper characteristics as with a coating color #2.

The papers coated with the reference colors were used to develop a calibration curve for surface strength as a function of the binder amount (shown in Appendix 2). If the two coating colors reach the assumed stabilization point at the same time there would be a significant difference in the surface strength, as shown in **Figure 3.**

If we assume that a papermaker is using the coating color #1 today, the optimization of the coating color by reducing the latex level from 10 parts to 9 parts will bring cost savings of 120.000 € per 100.000 tons of produced paper (calculated for single coated paper with ~30% of coating).

CONCLUSIONS

The coating color composition changes as a function of the time in all coating processes. The rate of the change and the time of the changes vary by the different processes. The differences in two separate processes can be illustrated as in **Figure 4**.

In real life coating processes the composition of the coating color in circulation is always different from the composition in the make-down. In reality there does not exist a process where the coating color composition in the circulation is the same as it is in make-down. Therefore, it is important to try to minimize the change rate and the time of the change in order to keep the paper characteristics, like surface strength, as constant as possible.

In this paper we have shown that there is a laboratory method which can predict difference in the change rate of the coating

colors. The laboratory method does not show the stability point, but the speed of the change can be evaluated. Due to the fact that all measurements are done with a laboratory scale coater, it can be expected that the observed changes are even bigger in full scale production. This has also been proven by comparing the results of the laboratory and the full scale(22). Similar phenomenon has also been seen when comparing the pilot scale and full scale results.

The coating color stability has a strong correlation with good runnability and the end product quality, but the most important influence it has in the cost. In the example in this paper the two coating colors had similar component structure. It could be estimated that the binder amount depleted from the coating color 1 was 2 pph
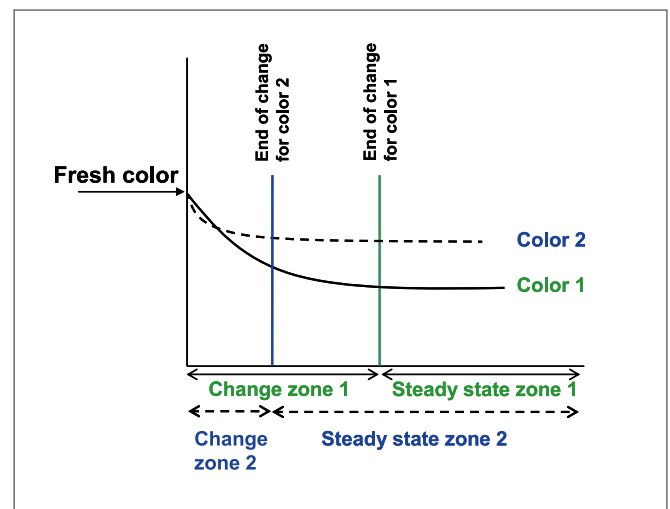

Figure 4. The time and the rate of change for two different coating colors

Table A. Base paper properties

Paper properties	Base web
Grammage, g/m²	80
Thickness, μm	100
Air permeability, Bendtsen, ml/min	640
Roughness, Bendtsen, ml/min	200

and the coating color 2 1.0 pph. Therefore, the optimization of the coating color design provides the papermaker a possibility to reduce the binder level with one part (assuming that he is using coating color 1 today). This will bring cost savings of 12.000 € per 100.000 tons of produced paper (calculated for single coated paper with ~30% of coating). This way the optimized performance leads also to maximized cost efficiency.

APPENDIX 1

Chemicals used in the study:

Covercarb 75, Omya, Hydragloss 90, KaMin, Dow XZ 96445.00, Dow Latex, Finnfix 5 and Finnfix 601, CP Kelco, Blancophor P, Ciba.

APPENDIX 2

Description of the used test methods

The coating color characterization has been performed with standardized handling at constant temperature (25°C).

Solids content of coating colors was measured with a Mettler-Toledo HR73 Halogen moisture analyzer.

Viscosities of coating colors were measured with Brookfield RVDV-II+ rotational viscometer (100 rpm) and with Eklund capillary viscometer (capillary size: 50 μm (0.5 mm).

Static water retention (ÅA-GWR) was measured using constant coating color volume 10 mL (5 μm membrane, 0.3 bar pressure, 2 minutes).

The inorganic/organic ratio impressed as the ash content was determined by burning the coating color at 425°C for 4 hours and measuring the weight loss.

The coating colors with different binder dosages (8, 9.4 and 10.7 pph) were prepared with same formulation to create standard curve (Figure A) for the binder amount based on the inorganic/organic ratio. With these coating colors, single coated papers with 11 g/m² coat weight were produced, and the IGT values were determined for these papers. A standard curve for binder amount *versus* surface strength was achieved as result (shown in Figure B).
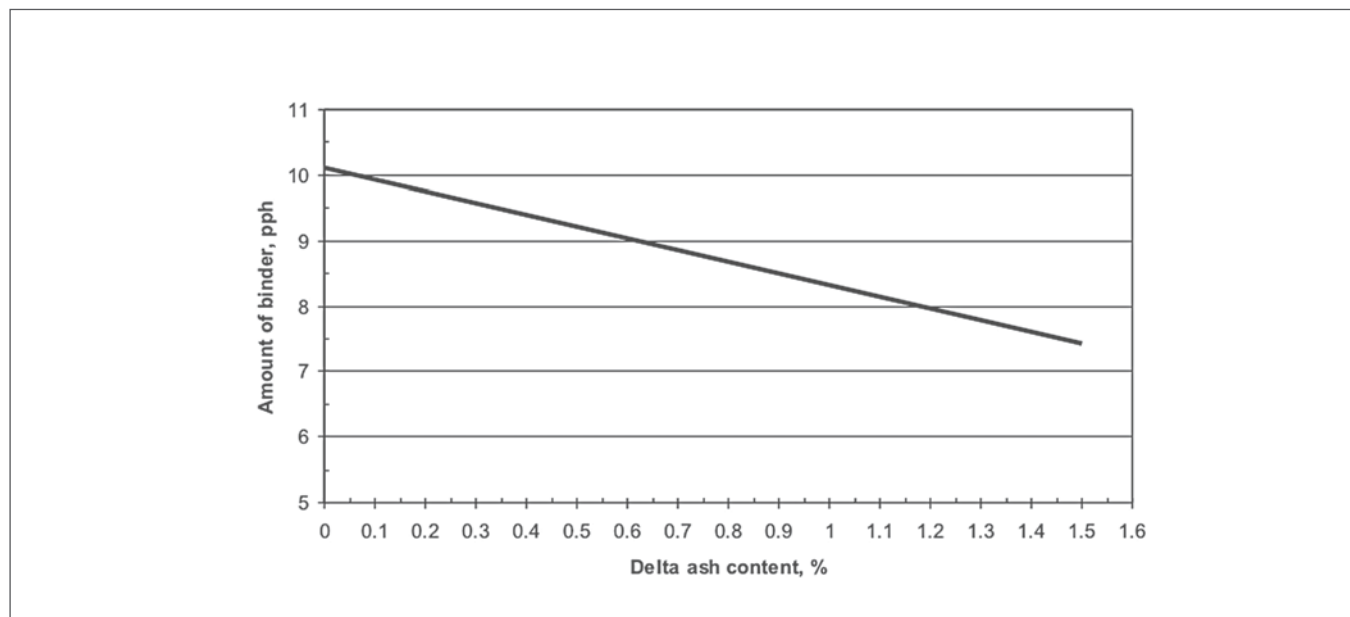

Figure A. The calibration curve – amount of binder as a function of delta ash content
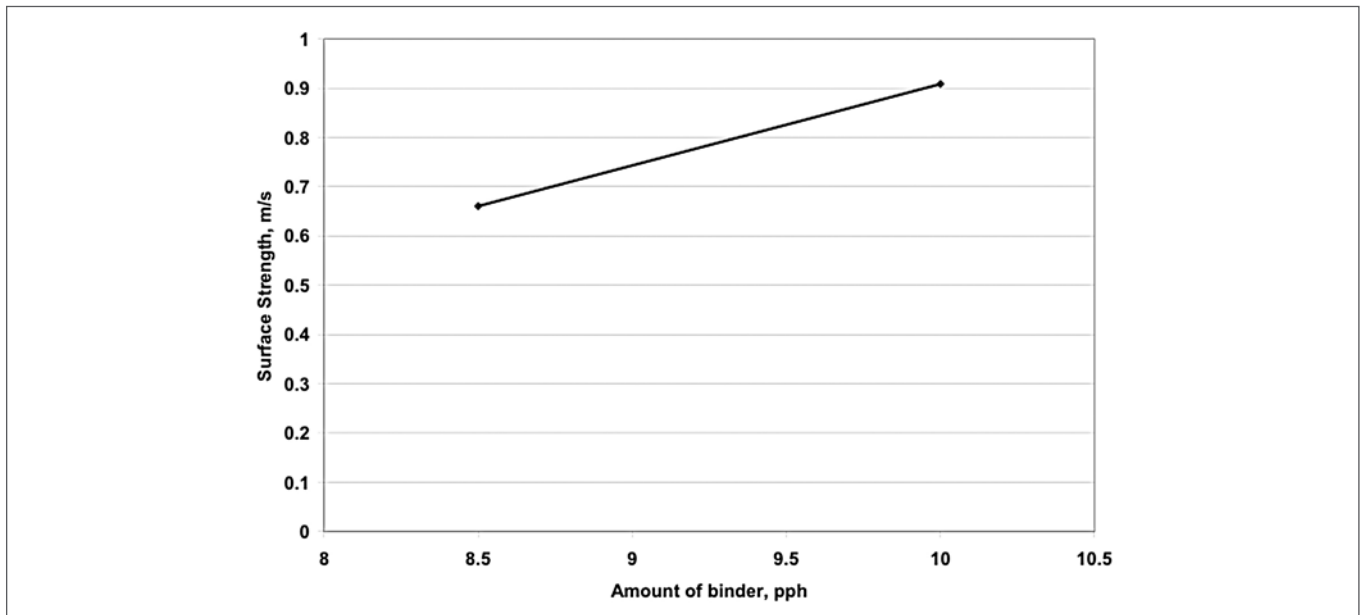
Figure B. The calibration curve – surface strength as a function of the binder amount

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