The research delved into the collective impact of calendaring and coat weight on the optical, surface, and printing characteristics of coated papers. A control bar coater was employed to apply coatings containing blends of paper coating pigments—Ground Calcium Carbonate (GCC), clay, and Precipitated Calcium Carbonate (PCC)—in ratios of 60:40:00 and 60:00:40, while maintaining a constant amount of additives. Various calendaring roll nips were utilized to examine how calendaring affected papers coated with different pigment blends. The findings revealed that coatings with PCC exhibited heightened bulk and opacity. Sheets with PCC displayed greater brightness compared to those with clay. While the gloss improvement effect was somewhat less pronounced in PCC coatings compared to clay, the impact of calendaring on ink holdout and paper surface strength was minor, yet more favorable for coatings containing PCC. Notably, a significant enhancement in print gloss was observed with higher proportions of PCC in the paper coating. Additionally, increasing coating weight contributed to the augmentation of desired properties.

**Keywords:** Coating, Calendering, Brightness, Delta Gloss, Opacity, Print gloss, Ink set-off.

1. **Introduction**

Calendering, a process involving the passage of paper through highly polished heated rollers, imparts a mechanical finish to enhance its properties. The response of pigment-coated paper to calendering is influenced by both the characteristics of the raw stock and the coating layer [1, 2]. When determining operating parameters, a balance must be struck considering the responsiveness of both the raw stock and the coating layer to calendaring action, often requiring compromises in setting operating conditions. The primary objective of calendering coated paper is to render the paper structure more conducive to printing [3]. Coated papers are primarily designed for high-quality products such as magazines, catalogs, and books, frequently undergoing multicolor printing processes where low roughness and a uniform surface pore size are crucial for optimal print results. Insufficient surface smoothness can result in subpar ink transfer and diminished print gloss, leading to unevenness in the printed image.

The impact of calendering is contingent on factors such as speed, moisture, temperature, the diameter and surface condition of the calendar rolls, and the linear load between the rolls and the coating component of the paper [4]. This process involves improving certain paper surface properties while sometimes compromising others, such as optical and strength properties. There exists a critical point in calendering where further alterations to paper and coating properties may cause degradation instead of improvement in quality [5]. Successful calendering hinges on achieving optimal surface properties without excessively impairing other paper properties. Hence, calendering outcomes are often assessed by comparing against paper properties like gloss, bulk, opacity, brightness, etc.

Several studies have reported on the effects of calendering on coated paper properties, demonstrating that it primarily increases gloss and smoothness while decreasing porosity. Conversely, calendering results in lower opacity and brightness, attributed to the compacting and rearrangement of the paper structure during the process [6, 7, 8]. Changes in paper and coating structures are evident, where coating pigment particle characteristics such as morphology, average size, and size distribution impact physical, optical, and printing properties. Within a given paper morphology, finer pigments contribute to higher gloss by forming a coating structure with a smoother surface and smaller pore sizes [2, 9].

Finer grade Ground Calcium Carbonate (GCC), traditionally used as a pigment, is a major component in coating color recipes due to its brightness and cost-effectiveness [10]. A small proportion of coating clay is added to enhance gloss, but it simultaneously affects the brightness and whiteness of coated paper. Precipitated Calcium Carbonate (PCC), with a narrow particle size distribution and a more open coating structure, provides a new option to replace clay up to 40% and elevate brightness to an optimal level [11, 12]. Thus, in this study,
GCC:Clay (60:40) and GCC:PCC (60:40) were employed as coating pigments, and coated paper underwent various degrees of calendering nips to investigate the impact of calendering on surface, optical, and printing properties.

2. Experimental Methodology

Materials & Methods
The evaluation of calendering effects on coated paper properties was conducted with a coat weight of 12 g/m² for batches containing the maximum amount of clay (40 parts) and PCC (40 parts) in the coating color, while maintaining a constant amount of GCC up to 60 parts. The entire procedure for coating and calendaring encompasses the following steps:

Preparation of Coating Color
The GCC-90 and PCC pigments were available in predispersed slurry and clay pigment was available as dry powder. For different pigments and pigment combinations, the amounts of binder and other additives were kept constant at the level. Measured quantities were added in the following sequence: pigment, dispersant (PA 40), rheology modifier (CMC), binder (starch) and insolubilizer (AZC). Each coating color was prepared for 400g pigment (dry basis) and the concentration of the coating color was targeted at 66.5 % of solids. The pH of the color was adjusted 8.5–9.0 using sodium hydroxide solution in desired quantity. The dispersant (PA-40) was used in the preparation of clay pigment slurry firstly. It was found by trial and error method a dispersant dose of 0.05 % gave minimum viscosity of the pigment slurries. Finally 2 coating color batches were named A, B having pigment blend proportions GCC: Clay: PCC in the ratio of 60:40:00, 60:00:40.

Application of Coating
The coating was applied to the top side of a 121 g/m² base paper by the means of laboratory K-coater. The coating dries by drainage into the base stock and also by evaporation dryers. So the coated sheets were immediately placed into an oven maintained at 105°C for 60 second to dry. Sheets were supercalendered in plant scale supercalender at BILT, SGU (Shri Gopal Unit) by applying a linear nip pressure of 76 bars, at 50 °C.

3. Analytical Techniques

Optical properties: 1% relative±Calendared coated/ uncoated sheets were conditioned at 27 humidity of 65±2% prior to testing of following properties as per the relevant standard methods listed below:
Grammage (g/m2) – ISO 534
Brightness (%) – ISO 2470
Gloss (at 75º) – Tappi 480 om 99
PPS roughness (micron) – ISO 8791/4
Opacity (%) – ISO 2471

Printing Properties:

Surface Strength: The surface strength was measured using IGT printability tester calculating VVP (Viscosity velocity product) Pick velocity can be derived in m/s from the velocity table belonging to the printability tester r with the formula: 
\[ Vp = 0.005 \times Ve \times d \]

Ve = set end speed (in m/s)
\[ d = \text{pick distance from beginning of the print} \]

Ink set off: A strip of the paper to be tested is printed with an IGT printability tester under standard conditions with a set off ink. After certain times the strip is brought into contact with a blank strip of a standard set off paper. Part of the ink, which is still present at the surface of the printed strip, will smear on the set off strip. The more ink is being absorbed into the printed strip; the less ink will smear on the set off strip. The density of the smeared ink will be a value for the absorption. Since smearing mainly concerns the ink, which is at the top of the surface of the paper. Ink setoff is measured using “IGT AIC2-5T2000, Global Standard Tester 2/3/3H”. The whole procedure is described in IGT leaflet W48 [13].
Print gloss: When ink is printed on paper a part of the ink is partially absorbed by the paper [14]. For the offset process this property is very important. If the ink is absorbed too slowly or too fast, it may result in a change of the dry ink properties. An absorption, which is too slow, may result in e.g. smearing because the ink does not dry fast enough. An absorption, which is too fast, may result in a reduction of e.g. gloss; in this case the absorption of the ratio of binding agent and pigments has been changed. A paper strip to be tested is printed with a standard gloss ink with the help of a printability tester. This information leaflet W49 describes a method to make a print to measure gloss for testing very smooth and smooth papers [13].

4. Results & Discussion

Effect of calendaring on paper properties

1. Bulk: Calendering compacts the paper, hence voids in between paper fibers and coatings get closed, which increase the bulk. The formulations containing GCC-PCC pigment blends give slightly bulkier sheets compared to other formulations containing clay. This may be due to steeper particle size distribution of PCC particles which produce an open coating structure with large air void volume.

2. Paper Gloss: As expected, when passing the paper from higher number of calendering nips, the load increases and results in reduced micro and macro roughness on paper surface due to leveling leading to increase gloss. The results revealed that increase number of nips regularly increases the gloss for coating recipe either containing clay or PCC. But gloss is found more with clay pigment due to its fine platy structure (Figure-1).

3. Brightness and Whiteness: Results reveal that optical properties like brightness and whiteness decreased as the number of nip were increased. There was a significant drop of brightness due to ill effects of calendering load. But loss of brightness was less in case of sheets coated with PCC (Figure- 2).

Fig 1: Effect on paper gloss
Fig 2: Effect on paper brightness

Fig 3: Effect on paper opacity

Fig 4: Effect on paper permeability
Decrease in whiteness was found more in case of sheets coated with coating color having clay.

1. **Scattering coefficient and Opacity**: Light scattering coefficient goes on decreasing with calendering load. It is due to formation of closed packed structure at higher load, hence pore volume becomes less. Less pore size scatters less light. Light scattering coefficient is found more in the case of PCC due to its open porous Opacity decreases due to calendering influence; it is due to decrease in light scattering coefficient. Also opacity in case of PCC is found more; this may be due to
maximum light scattering displayed by this coating formulation given an open coating structure (Figure 3).

2. **Permeability**: Calendering leads to compactness in fibers as well as coating layer, hence less air can penetrate through the paper surface. So permeability is reduced at higher degree of calendering. PCC has higher permeability due to its more porous structure (Figure -4).

3. **Effect on printing properties:**

4. **Surface strength (pick resistance)**: The pick strength was lowered with calendaring due to ill effects of moisture, temperature and pressure on paper surface. Coating having PCC proportions resulted into better surface strength (Figure- 5).

5. **Ink set-off**: Upon calendering paper gave more ink set off, ink setoff was found more in case of coating blend with higher proportions of PCC. It is due to its low ink absorption compared to coating blends with higher proportions of Clay (Figure-6). Hence PCC containing coating results into better ink holdout.

6. **Print gloss**: Print gloss was improved with higher degree of calendering. Improvement in gloss was more in case of coating color with higher proportions of PCC, due to its more open structure and lesser capillary action as compared to coating color with higher Clay proportions. (Figure-7)

5. **Conclusions**

1. Coatings containing GCC-Clay blends exhibit a relatively more significant improvement in gloss compared to coatings with GCC-PCC blends.

2. Formulations incorporating GCC-PCC demonstrate higher bulk and opacity than coating colors with GCC-Clay pigment blends.

3. Increased calendaring nip pressure correlates with a reduction in paper brightness. Additionally, under calendaring influence, the brightness and whiteness of a GCC-PCC coated sheet surpass those of a GCC-Clay coated sheet.

4. Coating formulations with higher proportions of PCC result in enhanced print gloss and ink holdout.

5. The GCC-PCC pigment blend displays superior responses to calendering in terms of pick strength, brightness, ink holdout, and print gloss, while GCC-Clay coatings exhibit improved paper gloss under calendering influence.

6. Augmenting coating weight contributes to the enhancement of paper properties and printability.

**References**


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