JOURNAL OF MATERIALS SCIENCE 39 (2004) 7327 – 7332

Mechanical properties of coated paper: Influence of coating properties and pigment Blends

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The effect of percentage solids content, coating film thickness and plastic pigment on mechanical properties of coated paper was studied. The results showed that the tensile strength, TEA, stretch and tensile stiffness were improved as the percentage solids content and the coating film thickness were increased. Bending stiffness slightly increased when solids content was increased and showed higher values on increasing the coating film thickness. The addition of plastic pigment to both clay based and GCC based coating mixtures improved the mechanical properties considered in this study. Although tensile strength and tensile stiffness increased with the addition of plastic pigment of smaller particle size, stretch and TEA showed a reverse trend.

1. Introduction

Paper coating is an important industrial process used to improve the appearance and printability of paper. Although the mechanical properties of paper coatings have a significant impact on the end use performance of coated paper, the emphasis has been put mainly on the printability of coated paper and the fluid dynamics of coating mixture.

The mechanical properties of coated paper are important in the examination of the bending and compressive deformation that coated paper undergoes in a printing press, e.g., paper handling and runnability [1, 2].

The knowledge of coating composition and its effect on the mechanical and optical properties might allow alterations of coating formulations to optimize performance among mechanical, optical and processing characteristics.

The mechanical properties of pigmented coating films are sensitive to changes in the type and morphology of the pigments, the properties of the binder, and the extent of the pigment coverage by the binder [3, 4].

Parpaillon *et al*. [3] found that the mechanical properties of clay-based coating film increased when using latexes of a high glass transition temperature. The elastic modulus of the coated paper decreases with increasing binder content when using soft latex but increases when using a hard binder such as starch [5]. The elastic modulus is high for pigment particles that have a large shape factor and small void volume. Kaolin usually has higher elastic modulus than calcium carbonate [6], but the moduli of the two pigments vary considerably and even overlap.

Despite hollow sphere plastic pigments have been used as partial replacements for inorganic pigments in paper coatings, little is known in literature about their effect on the mechanical properties of coated paper.

The main benefit of plastic pigments in paper coating is their impact on optical properties, sheet gloss and print quality performance. This benefit is primarily a consequence of the thermoplastic nature of the particles as they deform under the stresses applied during supercalendering to provide improvements in microsmoothness [7]. This improved calender response can also lead to less severe calender conditions and hence additional improvements in paper bulk [8].

This paper is aimed at the estimation of the effect of the coating properties and various coating pigments (including plastic pigments) on the mechanical properties of the coated paper.

2. Experimental

2.1. Materials

In this study a simple coating formulation comprising only pigment, dispersant and latex was used. The pigments were English China clay, SPS, obtained from Imerys, UK, and Ground Calcium Carbonate, Hydrocarb 90-ME 78%, pre-dispersed slurry supplied by OMYA Croxton + Garry.

The clay was dispersed in distilled water in the presence of 0.3 parts sodium hexametaphosphate dispersant at a solids content of 65% and a pH of 8.5.

The binder was 18 parts acrylic copolymer latex (Acronal S801, BASF). The solids content was adjusted to 50% and pH 8 (typical of general paper coating suspensions). This coating formula was employed with various coating film thicknesses and prepared at various solids contents.

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Two types of plastic pigment of different particle size (PP1, 0.4 micron and PP2, 1 micron, supplied by Rohm and Hass, Ltd.) were used at concentrations of 10, 20, 30, and 50% with clay, and ground calcium carbonate (GCC).

2.2. Viscosity measurements

The viscosity of the coating mixtures were measured using a rotary viscometer (Rheometer model ERV-8) at 100 rpm and 25°C. The viscometer measured the torque necessary to overcome the viscous resistance to the rotation. A direct read-out of viscosity in centipoises was given.

2.3. Preparation of coated paper samples

K-bar semiautomatic coater was used for applying the coating mixtures. All paper samples were supercalendered at 50°C and pressure of 87.5 KN/m in two nips using UMIST's pilot supercalender. All samples have the same film thickness (6 micron) except those prepared to study its effect. Various bars were used to apply various wet film thicknesses.

2.4. Mechanical properties measurements

The tensile properties of all paper samples were measured using an Instron 4411 universal testing machine according to TAPPI Test Method T 494 om-88. The test was carried out at 23°C and 50% humidity.

The tensile tester measures the load applied as a function of elongation of the sample strip. The tensile stiffness and bending stiffness were calculated according to the following equations [2, 9, 10].

$$\text{Elongation} = \frac{\Delta l}{l_o} \tag{1}$$

$$\text{Tensile stiffness } TS = \frac{\Delta F}{b} \cdot \frac{l_o}{\Delta l} \tag{2}$$

where F, tensile force (maximum force required); b, width of the test piece; Δl length increase of the test piece; and l_o, original length of the test piece.

The bending stiffness S_b can be calculated from the following equation:

$$S_b = \frac{Eh^3}{12} \tag{3}$$

where E, modulus of elasticity; h, thickness of the sample.

3. Results and Discussion

3.1. Viscosity of coating mixtures

As shown from Table I, increasing the percentage solids content of clay based suspension increased the coating mixtures's viscosity. The effect became more pronounced between 50 and 60% solids content. At High solids content the volume solids (i.e., solids per unit volume) decreased and there would not be enough water available to complete separating the pigment particles which enhanced the particle-particle interaction. As a result, higher stress is required to breakdown the internal structure and to initiate the flow than in the case of lower solids content mixtures [11].

TABLE I The viscosity of the coating mixtures, having various solids content at 100 rpm

Solids content	30%	40%	50%	60%
Viscosity (mPa·s)	20	36	46	186

TABLE II The viscosity of the coating mixtures (mPa·s), having various levels of plastic pigment, at 100 rpm

	Percentage plastic pigment				
Coating mixtures	0	10	20	30	50
(Clay/PP1)	45	50	55	70	81
(Clay/PP2)	45	48	50	66	70
(GCC/PP1)	32	40	49	54	56
(GCC/PP2)	32	35	39	44	50

Table II shows that the viscosity of coating mixture increased as the percentage of plastic pigment was increased. As plastic pigment is substituted for mineral pigment, volume solids increases due to density differences. The density of plastic pigment particles is between 0.2 and 0.4 that of clay. In other words, plastic pigment contributes between 2.5 and 5 times the volume solids as an equal weight of clay [12, 13]. This consequently influences the viscosity and the rheological properties of the coating mixture.

At the same solids content clay based mixture shows higher viscosity than GCC based one. Clay pigments have proven to be more structure creating than calcium carbonate, due to their shape, higher aspect ratio and layered characteristics [14, 15]. Coating mixture based on ground calcium carbonate does not create such structure, due to its limited interaction with the other components.

Plastic pigment of smaller particle size (PP1) showed higher effect on the viscosity of coating mixtures based on both Clay and GCC pigments than the larger one (PP2).

3.2. Mechanical properties

3.2.1. Tensile strength

Figs 1 and 2 show the effect of percentage solids content and coating film thickness on tensile strength of coated paper based on clay pigment. Increasing both solids content and coating film thickness led to an increase

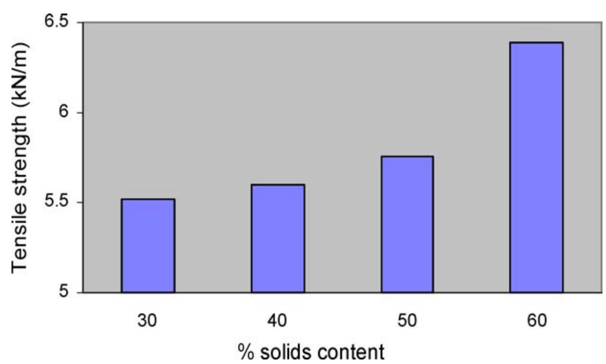

Figure 1 Tensile strength of paper coated with clay coating mixture having various solids contents.

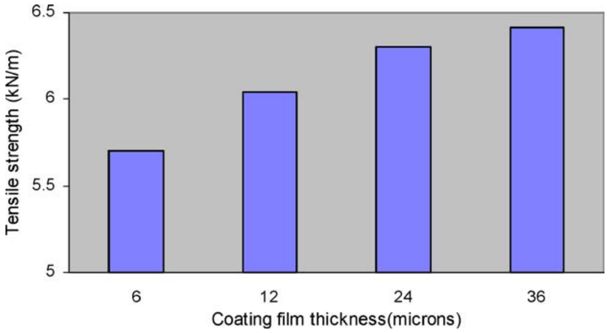

Figure 2 Tensile strength of paper coated with clay coating mixture at various film thicknesses at pH 8 and 50% solids content.

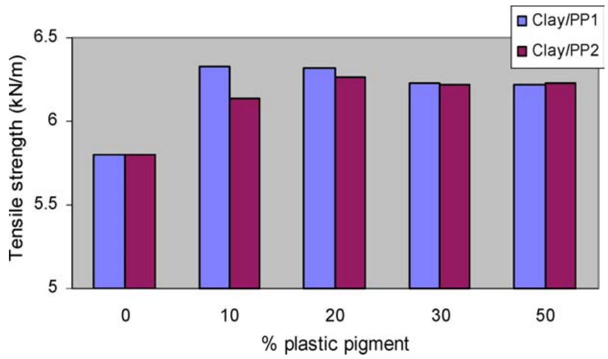

Figure 3 Tensile strength of paper coated with clay coating mixture having various levels of two types of plastic pigment (0.4 and 1 micron) at pH 8 and 50% solids content.

in tensile strength. High solids content coating mixtures and film thickness increased the dried coat layer and paper thickness consequently increased the tensile strength [16, 17].

The effect of incorporation of plastic pigment on tensile strength in clay based and GCC based coating mixtures is illustrated in Figs 3 and 4.

It is shown that the plastic pigment has higher effect on the tensile strength of the paper coated with GCC coating mixture than the clay one. The plastic pigment of small particle size (PP1) improved the tensile strength more than the larger one (PP2).

Increasing the addition levels of plastic pigment led to an increase in coating mixtures viscosity (Table II). This reduced the penetration of water to the base paper. In previous study [18, 19], it was found that the fibre network deformation during water contact causes both interfibre (fibre-fibre bond breakage and internal stress redistribution) and intrafibre (swelling) effects, depending on the paper characteristics and the contact time. This will have an effect on the final tensile strength and other mechanical properties.

The paper coated with clay based coating mixture has higher tensile strength than the GCC one. This is due to the flat clay platelets which can stack better than GCC [1] and the higher viscosity of clay based mixtures than GCC one at the same solids content.

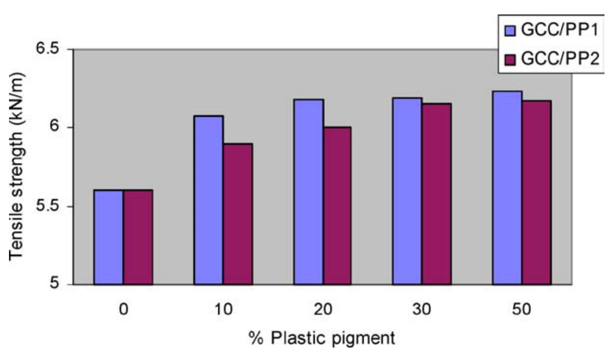

Figure 4 Tensile strength of paper coated with GCC coating mixture having various levels of two types of plastic pigment (0.4 and 1 micron) at pH 8 and 50% solids content.

3.2.2. Tensile energy absorption (TEA)

A very important mechanical property of coated paper is the surface strength. It is one of the most important quality parameters of a coated paper or board. It is critical for the success of the printing operation that the coating should be able to withstand the loads and deformations exerted on it in the printing stations in both the dry and the wet states. The surface strength can also be important in other situations, e.g., during calendaring and during different converting operations (folding etc.) where it is important that the coating should not crack [20]. The in-plane tensile strength of the coating cannot be used to predict the surface strength, since the pigment particles are more or less oriented in the layer due to the plate—like shape of the clay particles and the undefined shape of GCC particles. There is however an empirical relation between the fracture energy in the plane of the coating and the surface strength of coated product. The tensile energy absorption (TEA) was here used as a measure of fracture energy.

The TEA showed a pronounced increase with increasing both the solids content and coating film thickness following the trend as in tensile strength (Figs 5 and 6).

The TEA also improved with the addition of plastic pigment for both clay and GCC based coated paper (Figs 7 and 8). The effect of the particle size of plastic pigment showed a reverse trend to tensile strength. The PP1 has lower effect than PP2. The clay based coated paper showed higher TEA than the GCC ones as it is shown in Figs 7 and 8.

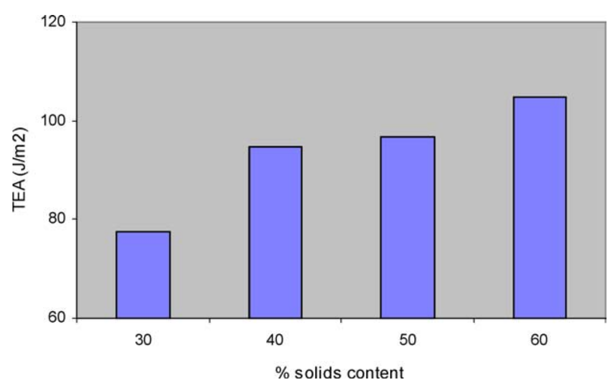

Figure 5 TEA of paper coated with clay coating mixture having various solids content.

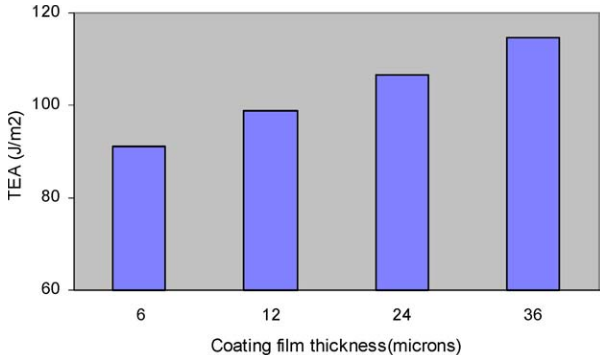

Figure 6 TEA of paper coated with clay coating mixture at various film thicknesses at pH 8 and 50% solids content.

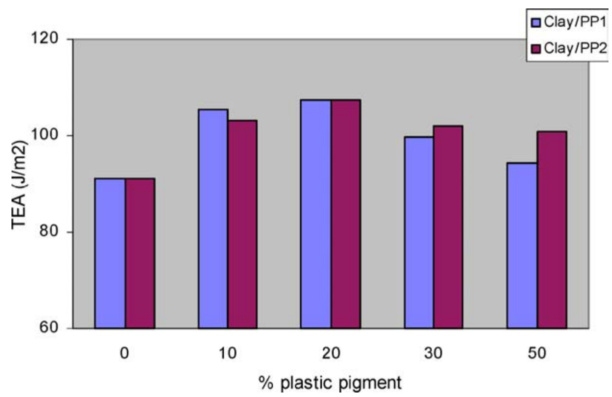

Figure 7 TEA of paper coated with clay coating mixture having various levels of two types of plastic pigment (0.4 and 1 micron) at pH 8 and 50% solids content.

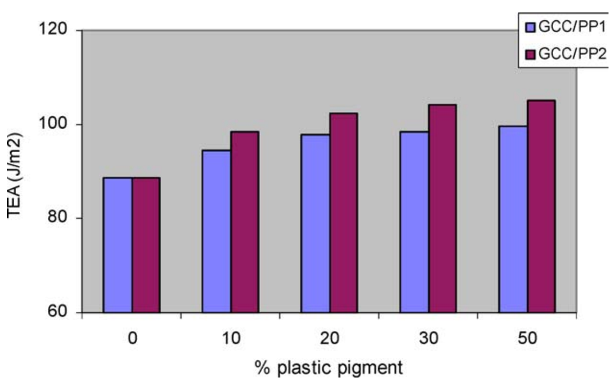

Figure 8 TEA of paper coated with GCC coating mixture having various levels of two types of plastic pigment (0.4 and 1 micron) at pH 8 and 50% solids content.

3.2.3. Stretch

The stretch of the coated paper obtained by changing both the solids content and coating film thickness improved and followed the same trend of the other mechanical properties considered in this work (Figs 9 and 10).

Figs 11 and 12 Show that the GCC based coated paper has lower stretch than clay one. Addition of plastic pigment has a pronounced effect in improving the stretch. However, stretch showed an entirely different behaviour from tensile strength and tensile stiffness. PP2 (1 micron) has higher effect than PP1 (0.4 micron).

A possible explanation for this observation is that, the amount of particles exposed on the surface starts to

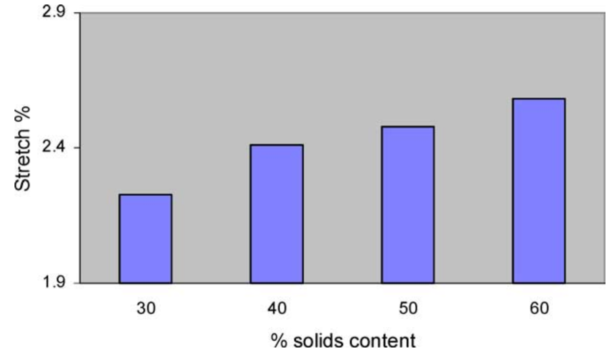

Figure 9 Stretch of paper coated with clay coating mixture having various solids content.

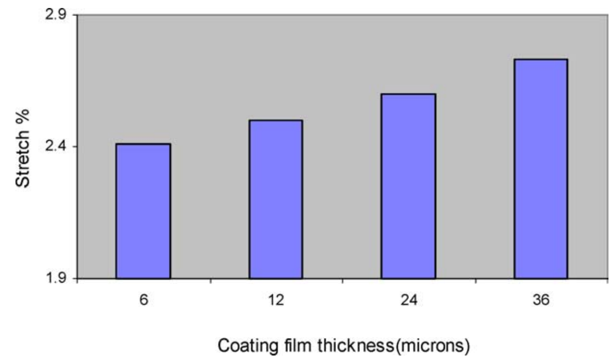

Figure 10 Stretch of paper coated with clay coating mixture at various film thicknesses at pH 8 and 50% solids content.

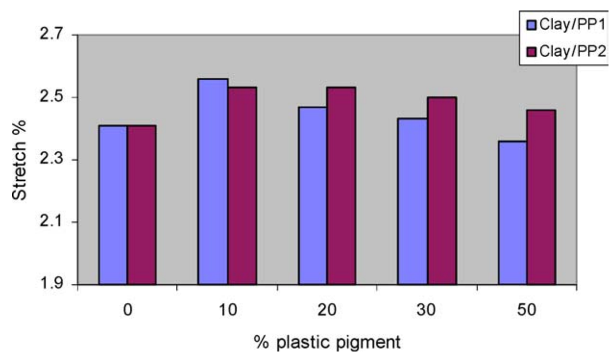

Figure 11 Stretch of paper coated with clay coating mixture having various levels of two types of plastic pigment (0.4 and 1 micron) at pH 8 and 50% solids content.

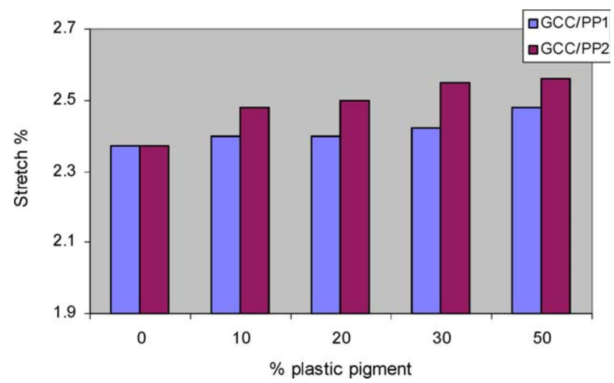

Figure 12 Stretch of paper coated with GCC coating mixture having various levels of two types of plastic pigment (0.4 and 1 micron) at pH 8 and 50% solids content.

increase on increasing the percentage levels of plastic pigment. Due to presence of voids in plastic pigment and their inherent thermoplastic nature, the pigments will deform under stress that is applied during the calendaring process.

Previous Scanning electron microscope study on the surface structure of coated paper having PP1 and PP2 showed that PP2 responded to calendering more easily than PP1. This is due to its higher particle size and all the pigments on the surface deform and flatten out [21], creating a semi plastic film on the coated paper surface. This can contribute to the total stretch property of the coated paper.

TABLE III Bending stiffness of paper coated with coating mixture having various solids content and coating film thickness

Paper parameters	Changes in parameters	Bending stiffness (mN·m)
Percentage solids content	30	0.128
	40	0.143
	50	0.151
	60	0.153
Coating film thickness (μm)	6	0.144
	12	0.151
	24	0.173
	36	0.191

3.2.4. Tensile stiffness and bending stiffness

Paper stiffness is a measure of the resistance of a given paper to bending. Thus tensile strength and stiffness are important in printing, handling and runnability of paper.

Paper stiffness is related to the flow properties because it depends on the ability of the layer on the outside curve of the material to stretch and on the ability of the inside layer of the curve to undergo compression [22]. Without stiffness, paper used in printing presses could not be easily fed through sheet fed machine. In web fed printing press good registration can only be maintained if the tensile stiffness is uniform across the width of the web.

The tensile stiffness of paper coated with coating mixtures having various solids content and various film thicknesses is shown in Figs 13 and 14, respectively. Increasing both the solids content and coating film thickness improved the tensile stiffness and the effect is more pronounced in the case of increasing the solids content. The bending stiffness is slightly increased in the case of solids content. The effect is higher on increasing the coating film thickness (Table III).

The addition of plastic pigment to coating mixtures increased the tensile stiffness for both clay and GCC based pigment (Figs 15 and 16). Plastic pigment has higher effect on clay based coated paper than GCC. The plastic pigment 1 (lower particle size) has higher tensile stiffness than the larger one following the same trend of tensile strength (Figs 3 and 4).

Table IV shows that the bending stiffness also is affected upon the addition of plastic pigment. The effect is much higher in the case of GCC.

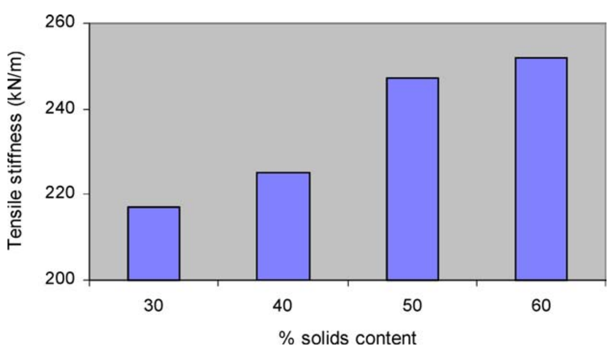

Figure 13 Tensile stiffness of paper coated with clay coating mixture having various solids content.

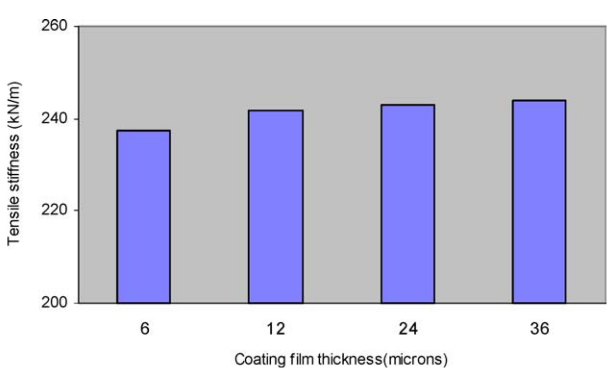

Figure 14 Tensile stiffness of paper coated with clay coating mixture at various film thicknesses at pH 8 and 50% solids content.

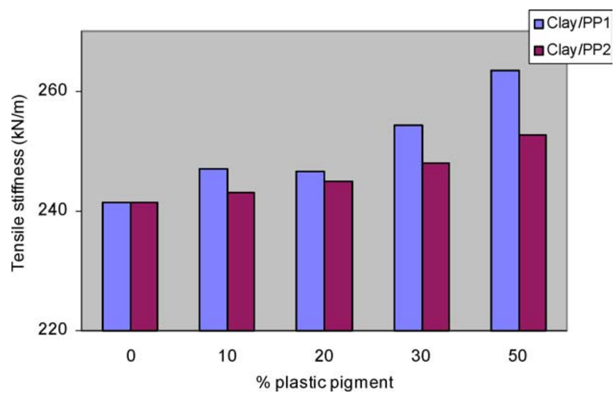

Figure 15 Tensile stiffness of paper coated with clay coating mixture having various levels of two types of plastic pigment (0.4 and 1 micron) at pH 8 and 50% solids content.

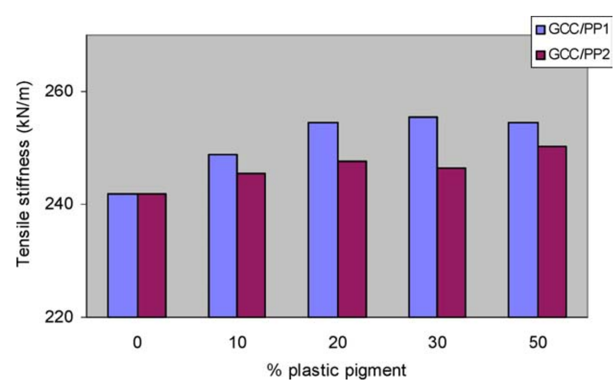

Figure 16 Tensile stiffness of paper coated with GCC coating mixture having various levels of two types of plastic pigment (0.4 and 1 micron) at pH 8 and 50% solids content.

TABLE IV Bending stiffness of paper coated with clay based and GCC based coating mixtures having various levels of plastic pigment

	% Plastic pigment				
Pigment blends	0	10	20	30	50
(Clay/PP1)	0.147	0.159	0.157	0.158	0.168
(Clay/PP2)	0.147	0.155	0.16	0.155	0.156
(GCC /PP1)	0.157	0.159	0.16	0.166	0.166
(GCC /PP2)	0.157	0.157	0.162	0.163	0.162

4. Conclusion

The effects of some coating parameters on mechanical properties of coated paper including tensile strength, TEA, stretch, and tensile and bending stiffness were investigated. Based on the results, we conclude the following:

- Increasing both the percentage solids content and the coating film thickness improved the tensile strength. The stretch, TEA, and tensile stiffness follow the same trend as the tensile strength. The greatest effect was obvious in the case of increasing the solids content. The bending stiffness slightly increased on increasing the percentage solids content but showed a marked increased as the coating film thickness was increased.
- The presence of plastic pigment showed a marked increase in all mechanical properties in the case of clay and GCC based coated paper.
- The effect of the plastic pigment particle size showed different results. Although the tensile strength and tensile stiffness showed higher values on using plastic pigment of smaller particle size, the stretch and TEA showed a reverse trend.
- The bending stiffness and TEA of the coated paper based on GCC have higher values than the clay based one, on contrary to the other mechanical properties considered in this study.

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Received 20 January
and accepted 30 June 2004