Effectiveness of Titanium Dioxide in Beater and Coating Applications

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EFFECTIVENESS OF TITANIUM DIOXIDE IN BEATER
AND COATING APPLICATIONS

by

Alptekin Akman

A Thesis submitted to the
Faculty of the Department of Paper Technology
in partial fulfillment
of the
Degree of Bachelor of Science

Western Michigan University
Kalamazoo, Michigan
September, 1966
ACKNOWLEDGMENT

The author wishes to express his appreciation to Dr. Robert A. Diehm and Western Michigan University Paper Technology Department, The New Jersey Zinc Company, American Cyanamid Company, and E. I. du Pont de Nemours & Company. Their assistance and guidance compiling this thesis was invaluable.
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INTRODUCTION

Titanium dioxide has been used as a filler and coating pigment in the manufacture of paper products for many years. In addition to its ability to make papers whiter and brighter, it is a most important opacifying material.

Since brightness, whiteness, and opacity are very important properties of paper, this report deals with beater applications where the pigment serves to brighten and opacify the sheet with minimum loading or filling, coating applications, and the combination of both. The effectiveness of the titanium dioxide is investigated by testing the coated and the loaded hand sheets for brightness, opacity, and gloss.
HISTORICAL BACKGROUND

Titanium dioxide was discovered late in the eighteenth century. It had very little acceptance as a pigment until after the first world war. Up to about 1940 the pigments manufactured were almost exclusively of the anatase crystal type.

In the early days of the second world war, rutile type of titanium dioxide was introduced because of the shortage of titanium pigments and their extraordinarily high opacity and tinting value. (1)

TITANIUM DIOXIDE

Production of Titanium dioxide:

Ilmenite is commonly used as the source for titanium dioxide. All ilmenites are chemical compositions containing titanium dioxide and iron oxides plus small percentages of various impurities.

"Digestion"—is the first step in producing titanium dioxide. Titanium slag is dissolved in concentrated sulfuric acid. The resultant cake is processed into "Black liquor." "Precipitation"—preparation of black liquor—clarification—purification—filtration.

"Calcination"—it is in a rotary furnace that the principal properties of TiO₂ (titanium dioxide) are created.

Crystal Structure:

The words "anatase" and "rutile" are basic types of crystal structures in which those pigments are produced. Both types are
odorless, non-toxic, fine white powders of very high brightness and opacity, insoluble in water and organic solvents. The principal difference in their properties is opacity. Both anatase and rutile crystals of TiO₂ are constructed of octahedra, such as this consisting of six oxygen atoms with a center atom of titanium:

To produce pigments of rutile crystal structures, anatase crystals can be converted to rutile by heating at temperatures above 700°C or they can precipitate rutile from the titanium sulfate solution by introducing rutile seeds.

The major difference between anatase and rutile structures, it is agreed, is the way in which the octahedra join together to build the crystal architecture. In anatase, two adjacent edges of the rectangular base of each octahedron are shared with corresponding edges of others.
### SOME PHYSICAL PROPERTIES OF TiO$_2$

<table>
<thead>
<tr>
<th>PROPERTY</th>
<th>ANATASE</th>
<th>RUTILE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific gravity</td>
<td>3.9</td>
<td>4.2</td>
</tr>
<tr>
<td>Refractive index</td>
<td>2.55</td>
<td>2.75</td>
</tr>
<tr>
<td>Melting point</td>
<td>inverts to rutile</td>
<td>1840° C</td>
</tr>
<tr>
<td>Dielectric constant</td>
<td>31</td>
<td>114</td>
</tr>
</tbody>
</table>

**Optical Properties:**

Using a suspension of pigment in water, Pfund, of Johns Hopkins University found that the light transmission of a constant weight of pigment decreases to a minimum as the average partial size is reduced to about (0.25) micron; further diminution in size results in higher transmission (3). As the average wave length of white light is 0.55 micron, it is apparent that optimum opacity (essentially the reciprocal of transmission) is obtained when the average particle size of the pigment is about half that of the light employed. As a result of such a theory, the optical properties of white pigments are dependent upon three factors:

1. Bright, white color
2. Fine particle size
3. High refractive index.

Using a large rutile crystal; (De Vore) showed that its refractive index is dependent upon two factors:* 1. wave length of the light;

2. the direction of entrance of light into the crystal in the visible

* Refer to Figures 1 A, B, C
spectrum (4000 Å - 7000 Å units wavelength). The refractive index of rutile is highest in violet light (4000 Å) and lowest in red light (7000 Å). Also it is higher when the light enters the crystal perpendicular to the main axis rather than parallel to it. (4) (5)

The refractive index of a multiplicity of fine crystals of rutile pigment in white light combines the effects of both of the above two factors. As indicated* the value is intermediate between the two lines at 5500 Å, the center of the visible spectrum. Thus this means refractive index of rutile titanium dioxide is (2.75).

Anatase titanium dioxide crystals are less effective than rutile in refracting light, as shown in Figure 3 with the result that the mean refractive index of anatase is approximately 2.55 (5).

Refractive Indices of Papermaking Materials

The refractive indices of paper constituents may be classified into three groups:

1. 1.00 Air
2. 1.50 fibers, impregnants, adhesives, common fillers
3. 2.55-2.75 titanium dioxide.

When light enters a sheet of white, unfilled, uncoated paper, it is reflected and refracted by one fiber after another with the result that part or all of the light is turned outward, giving brightness and opacity. The reflection and refraction are imparted by the difference in refractive index between the fibers and air (1.55 vs. 1.00).

*Refer to figure 2
If the paper were filled with clay, a thinner sheet would provide equal opacity because of the increased number of surfaces for reflection and refraction. To maintain the opacity at still lower basis weight, it is necessary to use a filler of higher refractive index as compared with air (2.55 vs. 1.00) provides a difference three times as large as that of fiber or clay (6).

**Opacity:**

The mathematical relationship between opacity and the refractive index of fine particles in a medium was determined by the formula of Fresnel:

\[ R = \left( \frac{n_1 - n_2}{n_1 + n_2} \right)^2 \times 100 \]

This formula furnishes a means of calculating the percent of a light beam reflected at the surface of a single particle (refractive index of \(N_1\)) in a medium of refractive index \(N_2\). Such reflectance generally bears a close relationship to opacity of a white pigment (6).

**Titanium dioxide in filled Papers:**

The principles established by Cyr and Kress (7) are employed today by every papermaker who uses opaque white pigments. They are:

1. New standards of brightness and opacity can be developed in paper through the use of opaque white pigments.
2. Such pigments are effective largely in proportion to their refractive index.
3. They are relatively more effective in papers of low basis weights because of the inherent higher opacity of heavier papers.
4. They offset the reduction in opacity due to calendering.
5. They offer the most feasible means of increasing the
brightness and opacity of impregnated papers.

6. They contribute high resistance to show-through of print.

Retention of TiO$_2$

It was originally expected that the retention of such pigments would be low because of the extreme fineness of their particles as compared with clay.

Cyr and Kress obtained relatively high retention. They reported that this retention cannot be due entirely to a mechanical filtering action. The retention is possibly caused by some force similar to absorption or attraction of the fibers for the particles.

The experimental procedure employed by (Haslam and Steel) was revealed (8) that opaque pigments are retained in two sheets by three possible mechanisms:

Filtration:

The particles of opaque pigments as well as most of the particles of clay are entirely too small to be retained by filtration to any important degree as single particles. Since single particles cannot be retained by filtration, any pigment so retained must be floculated. Floculations are favored by high pigment concentration, high pigment--liquid interfacial tension, and small particle size; it is decreased by the reverse of the above and by agitation.

The retention of a pigment by filtration should also be increased by sheet weight, by increasing in pigment--fiber loadings in the beater,
and by any conditions that tend to close-up the web, "it is immediately evident, therefore, that filtration is not the controlling factor in retention since it is a matter of common knowledge that the greater the amount of pigment furnished, the lower is the fraction retained."

Coflocculation:

Employing a new technique, Haslam and Steele obtained the first direct visual evidence that the phenomenon of coflocculation of pigment and fiber does exist. That is "pigment particles or groups of particles coming into contact with the surface of a fiber do adhere to the fiber with a force sufficiently great to withstand the rush of water past it as the web is formed. This process continued until at some point the load of pigment became too great to withstand the rush of water and a whole clump of pigment was lost, where upon the process began over again." "Coflocculation should be increased by those factors which increase the forces between the pigment and fiber, and between pigment and pigment. In Figure 4, 5, is shown the pronounced effect of alum on retention. Alum flocculated both pigment and fiber."

Mechanical Attachment:

When Haslam and Steel reported (8) "that most, if not all, of the pigment so attached was present in the hollow interior (lumen) of the fiber, usually sticking to the inside wall but in no sense embedded in the wall itself." The importance of mechanical attachment as a means of retention of pigment is shown in Figure 6-A.
**TiO$_2$ in Paper Coatings:**

While titanium dioxide is used as a filler in some substrates, most of the pigment is usually incorporated into the coating color. There are several reasons. There is no loss of pigment to the white-water system. Higher contents of titanium dioxide are readily formulated into coatings and the use of pigment in coatings permits employing substrates of lower brightness.

(9)

**Optical Properties of Titanium dioxide in Coatings:**

The brightness and opacity of conventional clay coatings depend in large measure on the entrapped air. The binder in coatings is insufficient in amount to fill all the space between the clay particles. As a result a multiplicity of minute air pockets form in the coating during drying and also binder (starch) and air, light that enters the film is reflected and refracted because of the difference in refractive index (1.55 clay and 1.53 for starch vs. 1.00 for air) at the interfaces. Thus part or all of the light is turned outward and the coating appears bright and a degree of opacity.

Replacement of part of the clay by titanium dioxide improves both brightness and opacity. The reasons are as follows:

1. The dry brightness of titanium dioxide is substantially more than that of clay.
2. TiO$_2$ provides many more particles for reflection and refraction of light than an equal weight of clay, because its particles are of much smaller size and in the optimum range for brightness and opacity.
3. Clay particles contribute significant opacity and brightness only when in contact with air, but not when surrounded by binder,
because the refractive indices of clay and binders are quite similar. TiO₂, however, imparts high opacity and brightness in either air or binder, because of its high refractive index.

These properties of TiO₂ not only impart high brightness and opacity to coatings, they also help to retain those features when the air pockets in the coatings are reduced in number, as in supercalendering, or when they are filled with wax, resins, or oils (as in bread wrappers, foodboards, or printing papers).
A light beam is displaced farther from its original path in going through rutile than anatase because it is bent more sharply at point "A".

The solid line illustrates how a beam of light going into a sheet or coating containing rutile is reflected sooner because it is bent a little more by each particle than it would be if the particle were anatase (dotted line). The less the light penetrates, the more opaque is the sheet or coating.
Figure 2
Refractive Index Curves for Rutile

Refractive Index

Light perpendicular to main axis

Mean Refractive Index of Rutile

Light parallel to main axis

Wavelength "Angstrom Units"
FIGURE 3

REFRACTIVE INDEX CURVES FOR ANATHESE

Mean Refractive index of ANATHESE

Light Perpendicular

Light parallel

WAVE LENGTH "ANGSTROM UNITS"
EFFECT OF "ALUM" ON RETENTION
OF TITANIUM DIOXIDE

% Alum on oven-dry pulp — 4% consistency

FIGURE - 4

% Alum on oven-dry pulp — 0.5% consistency

FIGURE - 5
FIGURE - 6

EFFECT OF TEMPERATURE ON RETENTION
OF TITANIUM DIOXIDE

Temperature °F

40  80  120  160  200

FIGURE - B

EFFECT OF AGITATION AND RECOVERY TIME ON RETENTION

A - No agitation
B - Plus agitation

Recovery Time - "Hours"
FIGURE 7

BRIGHTNESS RELATIVE TO TiO₂ CONTENT

% TiO₂ in sheet
FIGURE 8

TAPPI OPACITY RELATIVE TO "TiO₂" CONTENT

TAPPI OPACITY

% TiO₂ in sheet
FIGURE 9

EFFECT OF TITANIUM DIOXIDE OVER BRIGHTNESS
FIGURE 10

EFFECT OF TITANIUM DIOXIDE
OVER TAPPI OPACITY

TAPPI OPACITY

100
90
80
70
60
50
40
30
20
10
0

0 3 6 9
100 97 94

TiO₂ / clay ratio

10 % TiO₂
90 % Clay
EXPERIMENTAL WORK:
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EXPERIMENTAL PROCEDURES:

Titanium dioxide as filler:

A combination of 75 parts soft wood bleached kraft and 25 parts soft wood bleached sulfite pulp was beaten in a laboratory beater according to Tappi method (T-200), at I.58 consistency, to a Canadian standard freeness of 300. The beater roll was then raised and 1 per cent Pexol size, followed by 2 per cent alum based on dry fiber weight, were added and mixed for 5 minutes.

The hand sheets were made by using the British sheet mold (T-205) and the following per cent of titanium dioxide was added into the sheet machine container on dry weight of the fiber. Percentage added: 3 per cent and 6 per cent.

Titanium dioxide in coating - Preparation of clay slurry:

A master batch of 50 per cent clay slurry was prepared. The clay slip was sheared in a laboratory sized dough mixer at 60 per cent for 15 minutes. Thereupon, a definite quantity of water was added to produce a solid content 50 per cent.

Preparation of Titanium dioxide slurry:

Titanium dioxide (anatase) was obtained from The New Jersey Zinc Company. A master batch of 30 per cent solid TiO₂ slurry was prepared in the same way by adding 0.3 per cent dispersing agent.

Preparation of casein solution:

A 20 per cent casein solution was prepared by first adding defoamer to water and then adding casein slowly. The solution was first mixed for 15 minutes and heated slowly to 130° - 140° F. 28 per cent ammonium hydroxide solution was added and cooked for 20 minutes.
Preparation of Latex Solution:
A 48 per cent solid Latex (Dow 636) was obtained and used as 48 per cent solid in coating color.

Preparation of coating Color:
The required amount of clay and titanium dioxide slurries were weighed out separately according to the formulation and mixed. The casein solution was added slowly to the pigment slurry. After thoroughly blending the required amount of latex was added slowly and carefully. The total solids content of the coating color was adjusted to 45 per cent by adding water.

The formulations of all coating color have been listed in Table I.

Coating and Drying:
Each hand sheet was coated on the wire side with the coating color by means of the doctor rod drawdown method. The coating weights were calculated from their differences with the average weight of the uncoated sheets. The coating weight was controlled to yield 18 plus/minus 1 pound per 25 x 38 - 500 ream.

The coated sheets were air dried.

The double coated hand sheets first were coated with clay adhesive to yield coating weight of 10 pounds and followed by supercalendering and double coated with TiO₂-adhesive to yield coating weight of 10 pounds.

Supercalendering coated hand sheets:
The coated hand sheets were conditioned at 73°F and 50 per cent
relative humidity and supercalendered at nip pressure of 20 pounds by using the laboratory supercalender. The sheets were passed through the nip of the calender two times.

**Determining Physical Properties:**

**Brightness-A** photovolt brightness tester was employed to determine the brightness of the hand sheets in accordance with Tappi standard T 452 m.

**Gloss-A** Bausch and Lomb gloss meter was employed to determine the gloss of the samples. Tappi standards were followed as closely as possible.

**Opacity-** Opacity values were determined on a Bausch and Lomb opacimeter under test conditions specified in Tappi standard T-425 m-44.

**Fundamentals of Brightness:**

Pigments are the materials (10) used to provide the brightness and opacity required by paper and adhesives lower the brightness of the coatings because the refractive index difference between adhesives and pigments is less than between air and pigments. Therefore, the amount of adhesives should be kept as low as possible.

The surface smoothness of a coating can be improved by running it through a supercalender, but the packing of the coating decreases the amount of solids and thus decreases the brightness of the coating.

**Pigments:**

The pigments provide brightness and most of the weight of the
coating. Consider clay first. Commercial coating clay is purified to consist mainly of alumina (Al₂O₃) and silica (SiO₂) (11). It is one of the first pigments to be employed in the coating industry, its particle size and shape having been improved since then (12). A particle size of less than two microns predominates and hence the refractive index is higher, and has a brightness of about 85 percent when dry. Willets and Bingham suggested that titanium dioxide is to be blended with the clay to improve showing through. Moreover, clay is excellent in gloss, and is best in giving weight to the coating (13).

Benefits obtainable from replacement of Casein by latex:

In most cases it is found that latices used to allow a higher solids content and reduce the drying problem in the manufacture of coated paper. Since most latices are thermoplastic, they improve the gloss of the calendered sheet. Latices have also been used to obtain best pick resistance through partial substitution of casein by latex at a constant binder level (14).
# TABLE I

**TiO₂/Clay**

<table>
<thead>
<tr>
<th>Ratio</th>
<th>0%</th>
<th>3%</th>
<th>6%</th>
<th>10%</th>
<th>Ist</th>
<th>2nd</th>
</tr>
</thead>
<tbody>
<tr>
<td>20% Solid Casein (grams)</td>
<td>10 gm.</td>
<td>10 gm.</td>
<td>10 gm.</td>
<td>10 gm.</td>
<td>10 gm.</td>
<td>10 gm.</td>
</tr>
<tr>
<td>48% Solid Latex</td>
<td>30.0</td>
<td>30.0</td>
<td>30.0</td>
<td>30.0</td>
<td>30.0</td>
<td>30.0</td>
</tr>
<tr>
<td>50% Solid Clay</td>
<td>192.0</td>
<td>186.3</td>
<td>180.5</td>
<td>173.0</td>
<td>192.0</td>
<td>0.0</td>
</tr>
<tr>
<td>30% Solid TiO₂</td>
<td>0.0</td>
<td>9.6</td>
<td>19.2</td>
<td>32.0</td>
<td>0.0</td>
<td>320.0</td>
</tr>
<tr>
<td>Water</td>
<td>35.0</td>
<td>31.1</td>
<td>27.3</td>
<td>22.0</td>
<td>115.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Rod no.</td>
<td>9.0</td>
<td>9.0</td>
<td>9.0</td>
<td>9.0</td>
<td>8.0</td>
<td>8.0</td>
</tr>
<tr>
<td>Coating Weight (lb.)</td>
<td>18.0</td>
<td>18.0</td>
<td>18.0</td>
<td>18.0</td>
<td>10.0</td>
<td>10.0</td>
</tr>
<tr>
<td>Solid Content %</td>
<td>45.0</td>
<td>45.0</td>
<td>45.0</td>
<td>45.0</td>
<td>45.0</td>
<td>45.0</td>
</tr>
</tbody>
</table>
OBTAINED PHYSICAL PROPERTIES OF FILLED AND COATED HAND SHEETS

### TABLE II-A  FILLED HAND SHEETS

<table>
<thead>
<tr>
<th>TiO&lt;sub&gt;2&lt;/sub&gt;</th>
<th>Gloss</th>
<th>Opacity</th>
<th>Brightness</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.</td>
<td>1.9</td>
<td>60.4</td>
<td>68.6</td>
</tr>
<tr>
<td>3.</td>
<td>2.0</td>
<td>65.8</td>
<td>69.7</td>
</tr>
<tr>
<td>6.</td>
<td>1.9</td>
<td>68.5</td>
<td>70.0</td>
</tr>
</tbody>
</table>

### TABLE II-B  UNFILLED COATED HAND SHEETS

<table>
<thead>
<tr>
<th>Clay Ratio TiO&lt;sub&gt;2&lt;/sub&gt;</th>
<th>Gloss</th>
<th>Opacity</th>
<th>Brightness</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.</td>
<td>3.4</td>
<td>78.7</td>
<td>69.5</td>
</tr>
<tr>
<td>3.</td>
<td>3.3</td>
<td>80.1</td>
<td>70.5</td>
</tr>
<tr>
<td>6.</td>
<td>3.6</td>
<td>83.0</td>
<td>73.2</td>
</tr>
<tr>
<td>10.</td>
<td>3.6</td>
<td>83.5</td>
<td>73.9</td>
</tr>
<tr>
<td>Double coated</td>
<td>5.0</td>
<td>92.0</td>
<td>85.8</td>
</tr>
</tbody>
</table>

### TABLE II-C  3% FILLED COATED HAND SHEETS

<table>
<thead>
<tr>
<th>Clay Ratio TiO&lt;sub&gt;2&lt;/sub&gt;</th>
<th>Gloss</th>
<th>Opacity</th>
<th>Brightness</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.</td>
<td>3.3</td>
<td>79.0</td>
<td>69.1</td>
</tr>
<tr>
<td>3.</td>
<td>3.4</td>
<td>79.9</td>
<td>70.3</td>
</tr>
<tr>
<td>6.</td>
<td>3.6</td>
<td>82.7</td>
<td>73.3</td>
</tr>
<tr>
<td>10.</td>
<td>3.7</td>
<td>85.0</td>
<td>74.0</td>
</tr>
<tr>
<td>Double coated</td>
<td>5.3</td>
<td>92.5</td>
<td>86.6</td>
</tr>
<tr>
<td>Clay Ratio TiO₂</td>
<td>Gloss</td>
<td>Opacity</td>
<td>Brightness</td>
</tr>
<tr>
<td>-----------------</td>
<td>-------</td>
<td>---------</td>
<td>------------</td>
</tr>
<tr>
<td>0.</td>
<td>3.6</td>
<td>80.5</td>
<td>69.6</td>
</tr>
<tr>
<td>3.</td>
<td>3.4</td>
<td>81.5</td>
<td>71.0</td>
</tr>
<tr>
<td>6.</td>
<td>3.8</td>
<td>84.0</td>
<td>73.2</td>
</tr>
<tr>
<td>10.</td>
<td>3.8</td>
<td>85.5</td>
<td>73.8</td>
</tr>
<tr>
<td>Double coated</td>
<td>5.1</td>
<td>93.5</td>
<td>87.2</td>
</tr>
</tbody>
</table>
SUMMARY AND CONCLUSIONS OF EXPERIMENTAL DATA

This particular titanium dioxide pigment contributes substantially to the brightness of white paper stock. It shows opacifying efficiency in beater application. It is efficient in brightening.

**Brightness:**

The major function of titanium dioxide in paper is to increase opacity, reduce show-through, and reduce the weight of thin opaque papers, and the brightness of white paper stocks. Figure 15 shows the effect of increasing amounts of the titanium dioxide in hand sheets. Higher percentages of titanium dioxide will further enhance the brightness somewhat, but will be useful primarily to increase opacity.

**Opacity:**

The major contribution of the titanium dioxide to paper is opacity. Figure 16 shows the opacifying effect of increasing amounts of the titanium dioxide. The opacity show a gradual increase up to and beyond 6 percent of the pigment in hand sheets.

**Gloss:**

There is no effective gain in gloss of the hand sheets. Figure 17 shows the effect of increasing amounts of the titanium dioxide. The coated hand sheets show advantages in brightness, opacity, and gloss.
**Brightness:**

Changes in brightness of coated hand sheets resulting from increase in titanium dioxide to clay ratio are shown in Figure 18.

**Opacity:**

Figure 19 shows the effect in opacity of coatings containing different ratios of titanium dioxide to clay.

**Gloss:**

Figure 20 shows the glossing effect of coating different ratios of the titanium dioxide to clay.

**Double Coated Hand Sheets:**

In Figure 21 A, B, C, is shown that the brightness of the filled stock has been affected in final brightness of double coated hand sheets.

The graphs in Figure 22 show that there is greater increase in brightness by substitution of clay with titanium dioxide than substitution of fiber with titanium dioxide.

By comparison of the filled hand sheets with coated hand sheets, it is seen that in Table 2 this titanium dioxide is more efficient in coating application than in beater application.
FIGURE 15

EFFECT OF TITANIUM DIOXIDE
on Brightness of filled handsheets

BRIGHTNESS

% TiO₂ in handsheets
FIGURE 16

EFFECT OF TITANIUM DIOXIDE
on opacity of filled hand sheets
FIGURE - 17

EFFECT OF TITANIUM DIOXIDE

on Gloss of filled hand sheets
FIGURE 18-A

EFFECT OF COATING "clay/TiO₂"
on Brightness of unfilled handsheets
FIGURE 18-B

EFFECT OF COATING "Clay/TiO₂" on Brightness of 3% filled hand sheets
FIGURE 18-C

EFFECT OF COATING "Clay/TiO₂"
on Brightness of 69% filled handsheets
FIGURE 19-A

EFFECT OF COATING "Clay/TiC" on Opacity of Unfilled Hand Sheets
FIGURE 19-B

EFFECT OF COATING "Clay/TiO₂"
on opacity of 3% filled hand sheets
FIGURE 19-C

EFFECT OF COATING "Clay/TiO$_2$"
on opacity of 6% filled handsheets
FIGURE 20
EFFECTS OF "TiO$_2$/clay" coating on unfilled and filled handsheets.

A - Unfilled handsheets
B - 3% Filled handsheets
C - 6% Filled handsheets
FIGURE 21 - A-B-C

"CLAY-TiO₂" DOUBLE COATING EFFECTS ON
BRIGHTNESS, OPACITY, GLOSS OF FILLED
HANDBLETS

% TiO₂ in sheet

% TiO₂ in sheet

% TiO₂ in sheet
Figure 22

Effect of Titanium Dioxide on Brightness of Coated or Filled Handsheets

A - Unfilled-coated Handsheets

B - Filled-uncoated Handsheets

% TiO₂ in sheet or TiO₂/clay ratios

Brightness
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