Standard Test Method for Equivalent Black Area (EBA) of Dirt in Pulp, Paper and Paperboard by Image Analysis [1]

This standard is issued under the fixed designation D 6101; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

INTRODUCTION

The level of visible dirt present in pulp, paper or paperboard can impact its usefulness in a specific end use application. In such cases, the presence of visible dirt specks that are high in number, easily noticed in visual examination, or both, may detract more from the apparent usefulness of the paper material than does a lower number of specks, or specks that are less easily noticed by the eye. Both the number of dirt specks and their visual impact may be important. For someone controlling or monitoring the papermaking process, the absolute physical area of dirt, or the number of dirt specks present in an inspection area may be of greatest importance. For the end user of the paper material, the overall visual impression may be the critical parameter.

1. Scope

1.1 This test method covers the use of image analysis to determine the level of dirt in pulp, paper, and paperboard in terms of Equivalent Black Area (EBA) of dirt specks within the physical area range of 0.02 to 3.0 mm^2 reported in parts per million as well as the number of dirt specks per square meter of sample. Using the algorithm prescribed in this test method, the maximum dirt size is limited to 3.0 mm^2. Extention to other speck sizes (for example those greater than 3.0 mm^2 in physical area), may require changes in equipment, calculation procedures, or both, and is not covered in this test method. This test method cannot be used for physical area measurements since it does not correctly measure the dirt specks for that mode of measurement.

1.2 The specimen to be evaluated must have a brightness, as determined by Test Method D 985, of 30 % or greater. It may be necessary to reform some pulp sheets into handsheets if the surface is too rough or textured.

1.3 This test method is an instrumental equivalent of Test Method D 2019, TAPPI T 437, and TAPPI T 213, all three of which report the equivalent black area of dirt in parts per million, and TAPPI T 537, which reports the number of specks of 0.02 mm^2 or larger per square meter. This test method can be implemented using any image analysis system, provided that it meets the criteria specified herein.

2. Referenced Documents

2.1 *ASTM Standards:* [2]

D 585 Practice for Sampling and Accepting a Single Lot of Paper, Paperboard, Fiberboard, and Related Products

D 985 Test Method for Brightness of Pulp, Paper, and Paperboard (Directional Reflectance at 457 nm)

D 2019 Test Method for Dirt in Paper and Paperboard

E 122 Practice for Calculating Sample Size to Estimate, With a Specified Tolerable Error, the Average for Characteristic of a Lot or Process

2.2 *TAPPI Standards:*[3]

T 213 Dirt in Pulp

T 272 Forming handsheets for reflectance testing of pulp (sheet machine procedure)

T 437 Dirt in Paper and Paperboard

T 537 Dirt Count in Paper (Optical Character Recognition—OCR)

T 1206 Precision Statement for Test Methods

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

[1] This test method is under the jurisdiction of ASTM Committee D06 on Paper and Paper Products and is the direct responsibility of Subcommittee D06.92 on Test Methods.

Current edition approved Sept. 1, 2005. Published September 2005. Originally approved in 1997. Last previous edition approved in 1997 as D 6101 – 97.

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] Available from TAPPI, 15 Technology Parkway South, Norcross, GA 30092.

3.1.1 *dirt*, *n*—any foreign matter embedded in or on the sheet, which, when examined by reflected light has a contrasting, darker color to the sheet surface and has an equivalent black area of 0.02 mm^2 or greater as determined by this test method.

3.1.2 *equivalent black area (EBA)*, *n*—the area of one of the round black spots (brightness of 2.4 % measured by Test Method D 985) on the TAPPI Dirt Estimation Chart that has the same apparent area when examined visually upon its white background (brightness of 81.5 % measured by Test Method D 985) as does the dirt speck when examined visually upon the particular sheet in or upon which it is embedded.

3.1.2.1 *Discussion*—A larger "gray" dirt speck has the same visual impact as a smaller "black" one when viewed on the same sheet and under the same conditions. The equivalent black area (EBA) of a dirt speck determined visually is generally less than its physical area. The EBA approaches the physical area only as the speck becomes large. This definition of EBA is technically identical to that found in Test Method D 2019, T 213 and T 437, and this test method produces results that are the technical equivalent of those test methods.

4. Significance and Use

4.1 The visual impact of a dark speck on a light background varies as a function of the speck size. The calculation of this visual impact is done based on Ricco's law in this test method, and reported in terms of equivalent black area. As the dirt speck becomes sufficiently large, the equivalent black area of a black speck (brightness of 2.4 % as measured by Test Method D 985) on a white background (brightness of 81.5 % as measured by Test Method D 985) will approach the speck's physical area. The use of the equivalent black area calculation procedure in this test method is highly significant, as it provides data continuity of dirt measurement with procedures such as Test Method D 2019 and TAPPI T 437 which have been in use for over 50 years.[4]

4.2 Dirt is usually found on the surface of the sheet, however dirt particles that are imbedded may also be discernible by the eye in papers that are transparent or translucent. The level of visible dirt present in papers used in printing, writing, and other forms of communication may be both an aesthetic and performance requirement. For example, bond and writing papers may be subjected to close visual inspection in their intended use, but may also be required to perform on scanners, bar code readers, or other automated optical recognition devices where dirt above some critical level could impact performance.

4.3 Similar considerations may be appropriate for papers used in wrapping and packaging. In addition, special considerations may be required where such materials come in contact with foodstuffs, and where visible specks may be considered unacceptable.

4.4 Dirt in the form of gritty materials embedded in the sheet is a serious defect in many printing papers used in contact printing because of the pitting and wear that they can cause in printing plates. Such dirt can also occur in paperboard such as linerboard, and when present may cause significant reduction in bursting strength. Dirt of this type is not easily detected using this procedure, because there is little color contrast between the dirt speck and the background sheet.

4.5 In addition, the repeatability precision of this test method is significantly better than that of Test Method D 2019 or TAPPI T 437.

5. Apparatus

5.1 *Description of the Apparatus*:

5.1.1 *Detector*—The detector is densitometric with at least 256 gray levels (G.L.) of sensitivity with the physical pixel resolution having an effective area of 0.02 mm^2 or less. Precision improves with resolution. Therefore it is advisable to have as high a pixel resolution as is practical for the smallest dirt specks. The detector must view the specimen normal to its surface. The light is un-polarized and is concentrated in the visible portion of the spectrum such that 95 % of the detected light reflected from a white surface will be between 380 nm and 740 nm. The illumination must be diffuse or axially symmetric with an incident angle of 45 ± 5°; the uniformity of the illumination on the specimen stage before any software corrections must be within ±4 %. The specimen stage must be shielded to prevent influence from ambient light.

5.1.2 *Analyzer*—An analyzer incorporating "Equivalent Black Area" (EBA) calculations and using a technique called the "visual impact parameter" (see Annex A1).[4] This parameter permits the system to perceive dirt in the same manner as would a human judge.

5.1.3 *Calibration Plates*—Calibration plates must be matte and have at least one solid white area and a solid black area. Two other image areas containing a minimum of 16 dots each with a brightness difference to their background of 20 % and 55 %. Additionally, the calibration plates must meet the specifications in Annex A2. Calibration plates are available from TAPPI.

5.2 *Calibration*:

5.2.1 Turn on the light source. Allow the equipment to warm up and adjust the hardware settings according to the instructions or recommendations. If there is an adjustable focus on the detector, verify that the calibration plate image is sharply focused. The system will have reached a steady state condition when five consecutive GL readings are within 2 % of each other.

5.2.2 *Contrast Calibration*—Place the calibration plate with the greatest contrast flat on the stage. If a device is used to hold a sample flat on the stage, then this same device must be used to hold the calibration plate flat.

5.2.2.1 *Zero Adjust*—With the black square in the field of view, scan the black area on the plate, adjust the instrument to report a value of not less than 9 out of 255 gray levels or 3.5 % of the full gray scale. Successive scans of the black area must give results within ±0.4 % G.L. values.

5.2.2.2 *Span Adjust*—With the white square in the field of view, scan the white area on the plate, adjust the instrument to report a value not greater than 220 out of 255 gray levels or 86.3 % of the full gray level scale. Successive scans of the white area must give results within ±0.4 % G.L. values. A

[4] Jordan, B. D. and Nguyen, N. G., "Emulating the TAPPI Dirt Count with a Microcomputer," *JPPS*, 14(1), 1988, J16–19.

minimum of 210 G.L. resolution between the black and white squares is required. The gray level scale must be precise enough that each gray level corresponds to a step of not more than 0.5 % reflectance units.

5.2.2.3 Repeat 5.2.2.1 and 5.2.2.2 procedures iteratively until both specifications are achieved.

5.2.3 *Equivalent Black Area Calibration*—Measure each of the calibration plates. Verify that the EBA results measured and reported agree within 10 % of those stated on the data sheet supplied with the calibration plates. If they do not, then check the hardware. If necessary, verify the correct operation of the equipment with the manufacturer for its adherence to this test method.

5.3 *Maintenance*—Follow the manufacturers' instructions regarding the equipment maintenance.

5.3.1 The calibration plates should be stored in the dark or in a black plastic envelope to prevent discoloration and loss of contrast. They should be cleaned DRY to remove dust or lint. Avoid scratching the surface as this may cause the plates to be out of specification. Periodically measure the TAPPI brightness of the white square. If the calibration plates fall outside the specifications given in Annex A2, then they must be replaced.

5.3.2 Unless the ambient light changes, or the hardware settings have changed, it is not necessary to recalibrate the hardware for a particular analysis. It should be noted that, with time, light sources age and hence, there may be a loss of intensity. Thus, full calibration checks and hardware adjustments must be made as frequently as specified by the manufacturer.

6. Sampling and Test Specimens

6.1 *Acceptance Sampling*—Sample the paper or paperboard in accordance with Practice D 585.

6.2 *Sampling for Other Purposes*—The sampling and the number of test specimens depends upon the purpose of the testing. Practice E 122 is recommended.

6.3 *Test Specimens*:

6.3.1 *Paper and Paperboard*—From each test unit, select ten or ore sheets having a total exposed area (both sides) of at least 10 m^2. Keep the specimen sheets clean between two outer extra sheets.

NOTE 1—There may be instances where less than 10 m^2 is examined. This may be acceptable when the quantity of dirt in the paper or paperboard exceeds the minimum required to reach a chosen level of counting precision (see 7.3) and the sample is representative of the manufacturing process.

6.3.2 *Pulp*:

6.3.2.1 *Pulp Sheets*—From each test unit, select ten or more sheets having a total exposed area (both sides) of at least 10 m^2. Keep the specimen sheets clean between two outer extra sheets (see Note 1).

6.3.2.2 Some pulp sheets contain deep corrugations that may cast shadows or prevent consistent detection of the dirt specks at some locations in the sheet. Such pulp sheets must be reformed into handsheets for examination.

6.3.2.3 *Slush or Flash Dried Pulp*—Take a sample and form into specimen sheets in a carefully cleaned stainless steel sheet machine according to TAPPI T 272. Make a sufficient number of sheets so that they have a total exposed area (both sides) of at least 4000 cm^2. Restrain dry the sheets taking care to avoid contamination and wrinkling.

7. Procedure

7.1 Carefully brush away any loose surface dirt specks. If the specimen is of low basis weight, like tissue, it may be necessary to back the specimen with a clean white sheet of paper before making the measurements. Avoid measuring samples that contain smudge marks, wrinkles, or both, as these could dramatically affect the results.

7.2 Follow the measurement procedure outlined in the instruction manual provided by the instrument manufacturer. Care should be taken to ensure that the specimen is held flat enough so that all dirt specks in the field of view are in focus (see 6.3.2.2).

7.3 Choose a consistent target of counting precision and measure enough paper surface to reach that precision.

7.3.1 By the nature of sampling randomly distributed dirt, if one sheet of paper is found to contain N dirt specks, then replicate sheets of paper from the same lot should be found to contain $N \pm \sqrt{N}$ dirt specks two times out of three. For example, if a certain area of paper is found to contain 100 dirt specks, another region with the same area should have 100 ± 10 dirt specks, or a counting precision of 10 %. If another specimen only contains 25 dirt specks, then replicate areas should contain 25 ± 5 dirt specks for a counting precision of 20 %. Therefore, to reach a consistent target of 10 % in the dirt count, one measures as much paper surface as needed to reach a minimum count of 100 dirt specks.

7.3.2 The precision of EBA in parts per million (PPM) is more complicated to estimate than the counting precision of the dirt count, because the total count is inflated by many small dirt specks that contribute relatively little to the total EBA in PPM. To reach a target precision on EBA in PPM one should count at least twice as many dirt specks as would be needed to reach the same precision in the particle count. For example, one would count 200 dirt specks to reach a 10 % precision on EBA in PPM.

8. Report

8.1 Report the following information:

8.1.1 The total equivalent black area as parts per million,

8.1.2 The total dirt count per square meter,

8.1.3 The % uncertainty, P, given by:

$$P = \frac{100\ \%}{\sqrt{N}} \quad (1)$$

where N is the total accumulated dirt count.

8.1.4 If the samples are pulp, report if the test was made or pulp sheets or handsheets,

8.1.5 Any deviations from this method, and

8.1.6 The minimum size counted, if a minimum size other than 0.02 mm^2 has been used.

NOTE 2—The average EBA should be calculated from the equivalent black areas of the individual dirt specks. In the visual technique (Test Method D 2019), it is necessary to sort the dirt into size categories and to calculate the average from the nominal size associated with each category. If the size categories are too coarse, or if the dirt distribution is highly skewed, then the calculation of the mean from the size histogram may overestimate the average by several percent.

9. Precision

9.1 See Table 1.

9.2 The repeatability (within one laboratory) of the EBA PPM for newsprint = 10 %, for linerboard = 27 %, and for pulp 5 to 43 %. The repeatability of the number of specks per square meter for newsprint = 11.5 %, for linerboard = 24 %, and for pulp 5 to 50 % in accordance with the definition of repeatability in TAPPI T 1206. These numbers are based on a study of four different specimens on one instrument with one operator and five replicates. The reproducibility (between laboratories) is not known.

TABLE 1 Data for Five Repeats with the Same Instrument and Samples (different fields with total area of 480 cm^2)

Trial	Pulp No. 1			Pulp No. 2			Newsprint			Linerboard		
	EBA, ppm	No. of specks per m^2	% uncertainty	EBA, ppm	No. of specks per m^2	% uncertainty	EBA, ppm	No. of specks per m^2	% uncertainty	EBA, ppm	No. of specks per m^2	% uncertainty
1	6	363	31.62	296	17 313	6.36	53	2723	8.98	17	856	16.01
2	9	544	25.82	313	18 154	6.21	56	2876	8.74	14	790	16.67
3	7	508	26.73	287	16 892	6.44	54	2636	9.13	15	834	16.22
4	6	363	31.62	279	16 822	6.45	51	2691	9.21	14	834	16.22
5	3	145	50.00	298	18 014	6.24	52	2657	9.09	17	988	14.91
Average	6.20	384.60	33.16	294.60	17 439.00	6.34	53.20	2 696.40	9.03	15.40	860.40	16.01
Std. Deviation	2.17	157.30		12.78	620.01		1.92	111.13		1.52	75.25	
% COV	35.00	40.90		4.34	3.56		3.62	4.12		9.85	8.75	
% Repeatability	43.32	60.67		5.37	4.40		10.02	11.42		27.28	24.23	

10. Keywords

10.1 brightness; dirt; dirt count; equivalent black area (EBA); image analysis; paper; paperboard; pulp

ANNEXES

(Mandatory Information)

A1. MEASUREMENT CONVENTIONS USED IN THIS TEST METHOD

A1.1 *The Center-surround Filter*—First, the digitized image is filtered with a“ center-surround” filter. If the intensity of the picture point at each location (i, j) is called X (i, j), the average background in a 1.0 mm^2 area centered on the point (i, j) is called $<X(i, j)>$ then the filtered intensity $Y(i, j) = X(i, j) - <X(i, j)$. There are various ways to estimate the background intensity $<X(i, j)>$ but any picture points inside a dirt speck should be excluded from the estimate of $<X(i, j)>$. If all the potential filter points fall within a dirt speck, then other means may be explored to sense the background immediately around the dirt speck (within 0.5 mm of the speck perimeter). For example, it may be necessary to expand the width of the background filter only at these locations where the usual filter is entirely within a very large speck.

A1.2 *The Contrast Threshold*—The threshold T is the grey level increment corresponding to a difference of 10 % brightness. Each picture point (i, j) is considered “detected” as a part of a speck if $Y(i, j) > T$.

A1.3 *The EBA*—The EBA of a speck is proportional to the sum of the $Y(i, j)$ values for all “detected” picture p points:

$$EBA = k \sum_{(i,j)\supset(Y(i,j)\geq T} Y(i,j) \tag{A1.1}$$

A1.3.1 The constant of proportionality is determined by the calibration procedure that follows. The total EBA is the sum of all the EBA values from the individual specks.

A1.4 *The Calibration Plates*—The original EBA scale was established by the TAPPI Dirt Estimation Chart used in Test Method D 2019 and T 437. A 1.0 mm^2 dot on that card has an EBA of 1.0 mm^2 by definition. The Rico’s law parameter Y of such a dot equals the nominal area multiplied by the difference in reflectance of the white card and the black ink. This reflectance difference is 83 %. The calibration plates used for the present method each have their own assigned value of reflectance difference between background and dot. For example, one of the plates may have an assigned reflectance difference of 20 %, which is only one quarter as contrasty as the dots on the original dirt estimation chart and a dot on that plate with a physical area of 1.0 mm^2 would have a nominal EBA of 0.25 mm^2.

A1.4.1 Each calibration plate contains 16 dots with physical areas ranging from 0.04 mm^2 to 1.5 mm^2. The nominal EBA of each dot will be given by:

$$EBA \text{ (nominal)} = \text{(stated physical area)} \times \tag{A1.2}$$

$$\frac{(\text{background brightness} - \text{spot brightness})}{83\ \%}$$

A1.5 *The Calibration Process*—Calibration involves determining the calibration constant *k* in the calculation of EBA. Use the instrument to measure the EBA of the 16 dots on the calibration plate with the calibration constant *k* temporarily reset to 1.0. Determine the proper calibration constant *k* as the ratio of the nominal EBA to the measured EBA of the 16 dots on the plate:

$$k = \frac{\text{nominal } EBA}{\text{measured } EBA} \quad \text{(A1.3)}$$

Equivalently, *k* is the slope of a plot of nominal EBA versus measured EBA for the 16 dots.

A1.5.1 If the instrument is functioning well, such a plot should be a good straight line, and the *k* value determined from the lighter calibration plate should agree well with the *k* value determined by a darker plate.

A2. FIGURES SHOWING DETAILS OF THE CALIBRATION PLATES

A2.1 See Figs. A2.1 and A2.2 for specifications and drawings of the calibration plates.

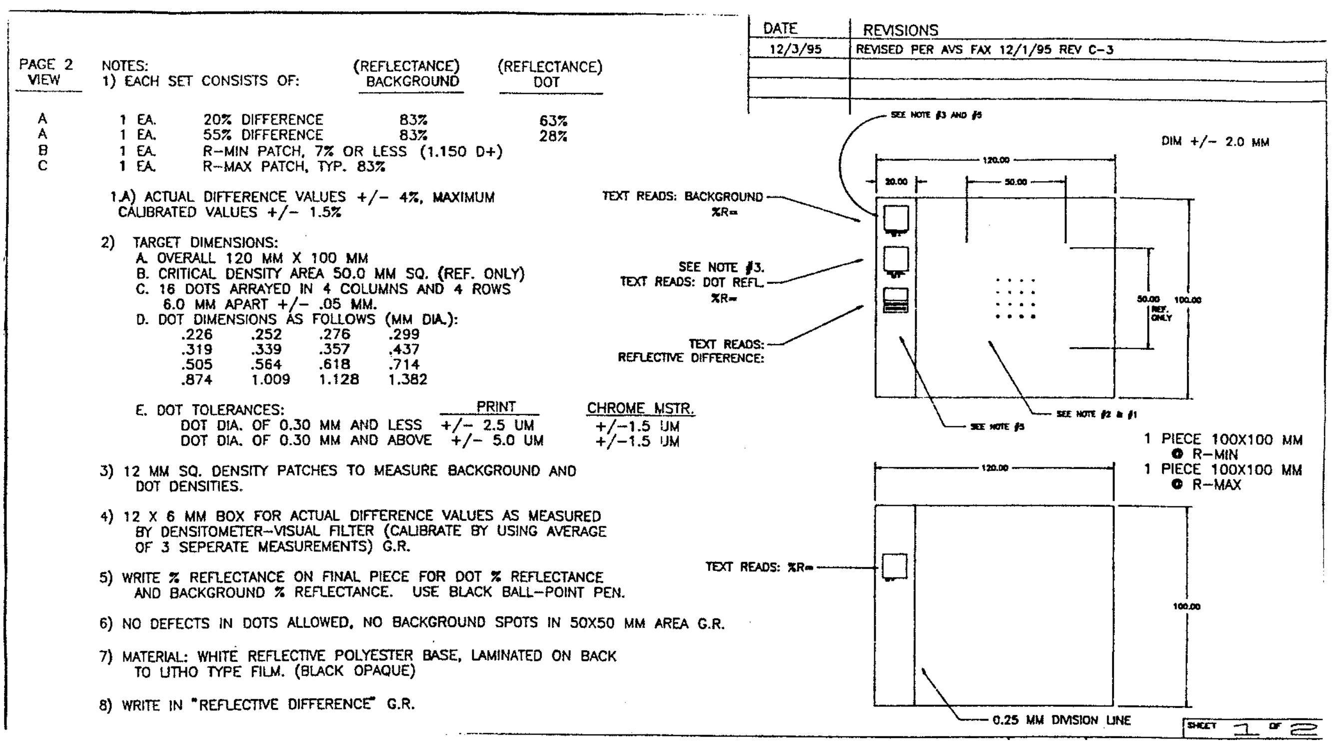

FIG. A2.1 Calibration Plate Specifications

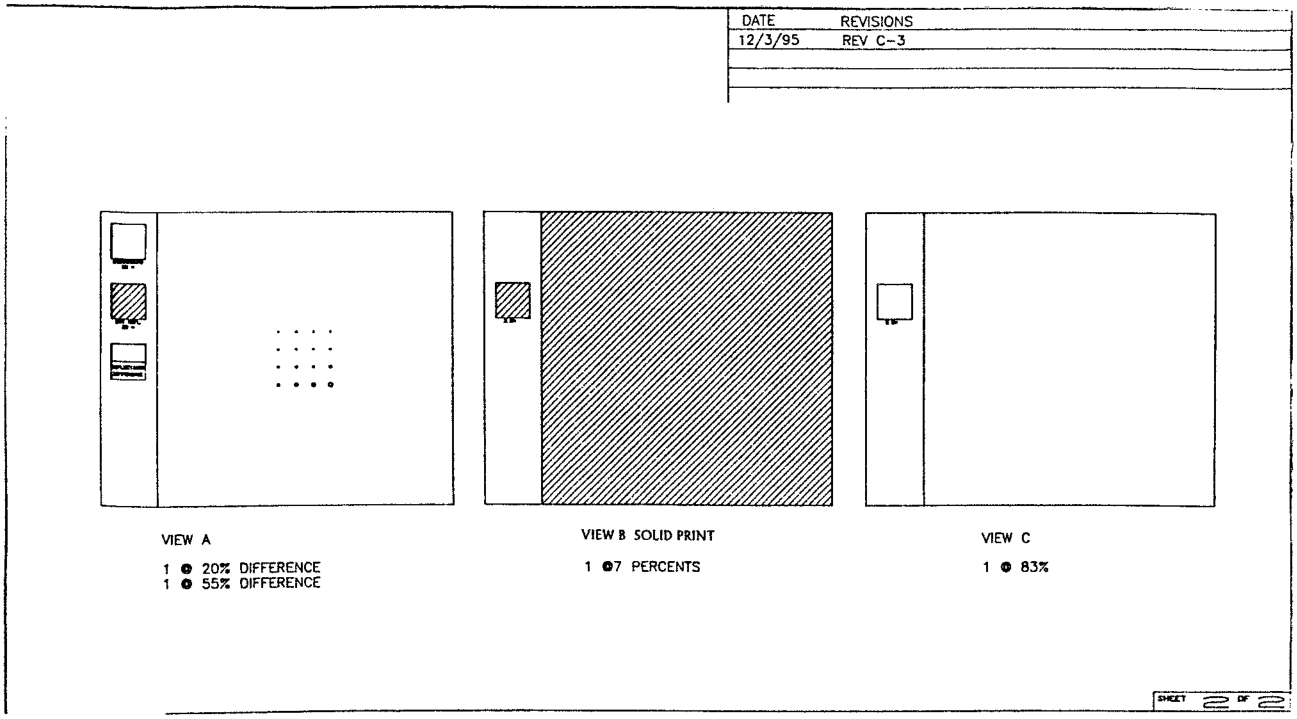

FIG. A2.2 Drawings of Calibration Plates

BIBLIOGRAPHY

(**1**) Jordan, B. D., and Nguyen, N. G., "Dirt Counting with Image Analysis," JPPS, 9(2) TR60–64, 1983.

(**2**) Jordan, B. D., and Nguyen, N. G., "Dirt Counting with Microcomputers," JPPS, 11(3), J73–78, 1985.