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RELATED
METHODS _____ See "Additional Information" _____

CAUTION:

This Test Method may include safety precautions which are believed to be appropriate at the time of publication of the method. The intent of these is to alert the user of the method to safety issues related to such use. The user is responsible for determining that the safety precautions are complete and are appropriate to their use of the method, and for ensuring that suitable safety practices have not changed since publication of the method. This method may require the use, disposal, or both, of chemicals which may present serious health hazards to humans. Procedures for the handling of such substances are set forth on Safety Data Sheets which must be developed by all manufacturers and importers of potentially hazardous chemicals and maintained by all distributors of potentially hazardous chemicals. Prior to the use of this method, the user must determine whether any of the chemicals to be used or disposed of are potentially hazardous and, if so, must follow strictly the procedures specified by both the manufacturer, as well as local, state, and federal authorities for safe use and disposal of these chemicals.

Roughness of Paper and Paperboard (Sheffield Method)

(Five-year review of Official Method T 538 om-22)

1. Scope

This method is a measurement of the air flow between the specimen (backed by flat glass on the bottom side) and two pressurized, concentric annular lands that are impressed into the sample from the top side. The rate of air flow is related to the surface roughness of paper or paperboard.

2. Summary

The measuring head, which has concentric annular lands, is dead-weight loaded against the specimen, which is supported by a flat glass surface. Air pressure is supplied to the zone between the annular rings that form the lands, and the flow rate of air that leaks between the surface of the paper and the metal lands in contact with the specimen is measured. The purpose of this test is to measure the extent to which the surface of a specimen deviates from a plane, as affected by the depth, width and number of departures from that plane. The measured flow rate of the leakage of air is an indirect measurement of surface roughness. This method does not provide an absolute measure of physical

roughness of the sample; rather it indicates a relative roughness to facilitate between materials. The effective measuring range of this method is from 0 to approximately 445 Sheffield units.

3. Significance

3.1 Surface roughness has an important influence on the printing quality, as uniform ink coverage of the paper can be achieved only when the deepest depressions of the paper surface under impression are separated from the printing plate by not more than ink film thickness on the plate. Roughness also affects properties such as the coefficient of friction, gloss, and coating absorption.

3.2 This method describes a procedure for obtaining surface roughness data quickly, using a measuring head with air passages that can easily be inspected for blockage, and easily cleaned.

3.3 In addition to the air that leaks between the lands and the surface of the specimen, there is some leakage through the specimen due to its porosity and also to the roughness of the underside of the sheet. The degree to which the test results are affected is related to the air permeance and compressibility properties of the specimen.

3.4 The air pressure that is supplied to the zone between the annular rings does not remain constant for the wide range of air flows that are within the capability of this test. Table 1 shows the relationship between pressure and flow.

3.5 The force with which the annular rings (lands) are loaded against the sample increases as the air pressure decreases. This is due to the force component (pressure times effective pressure area) that acts in an upward direction, opposite to the direction of the force of the dead weight.

3.6 If significant thickness variations are present in a specimen that is otherwise relatively smooth, the measured roughness value will be higher than that which is measured on a similar surface that has uniform thickness.

4. Apparatus

The apparatus consists of an air supply, a pressure controller, a pressure measuring device, an air flow measuring device, and a test head assembly which houses a flat plate, the measuring head, and a mechanical device that lowers the test head onto the specimen that is inserted between the measuring head and the flat plate.

4.1 An *air supply*; free of oil, water, and other contaminants, capable of supplying the necessary flow and pressure to the system, as recommended by the instrument manufacturer.

Table 1. Air pressure between the annular test lands when the test head is loaded onto the specimen

Flow (mL/min) ⁽¹⁾	Pressure (kPa)	Flow (mL/min)	Pressure (kPa)
0	9.85	1700	7.20
100	9.80	1800	6.95
200	9.70	1900	6.70
300	9.60	2000	6.45
400	9.50	2100	6.20
500	9.35	2200	5.90
600	9.20	2300	5.60
700	9.05	2400	5.30
800	8.90	2500	5.00
900	8.70	2600	4.65
1000	8.55	2700	4.30
1100	8.40	2800	3.95
1200	8.20	2900	3.60
1300	8.00	3000	3.20
1400	7.80	3100	2.75
1500	7.60	3200	2.30
1600	7.40	3300	1.90

Notes:

- (1) Flow is measured in milliliters per minute (mL/min), referenced to 21°C and 760 mm Hg.
- (2) Pressure shown is gauge pressure.

4.2 A *measuring head*, on the under surface of which are concentric annular lands of a total area of $97 \pm 3 \text{ mm}^2$ ($0.15 \pm 0.005 \text{ in.}^2$) and each land being $0.380 \pm 0.010 \text{ mm}$ ($0.015 \pm 0.0004 \text{ in.}$) wide. The outer diameters of the outer and inner lands shall be $47.07 \pm 0.03 \text{ mm}$ ($1.853 \pm 0.001 \text{ in.}$) and $34.37 \pm 0.03 \text{ mm}$ ($1.353 \pm 0.001 \text{ in.}$), respectively. The lands shall be made of, or finished with a corrosion resistant material (i.e., stainless steel or chromium plating), and the finished surface shall be optically flat. The total mass of the measuring head shall be $1.640 \pm 0.005 \text{ kg}$.

4.3 A “*glass surface*” plate, sufficiently flat so that no greater than 10 mL/min (approximately one Sheffield unit) of air flow variation shall be detected as the measuring head is moved over the working area. The maximum leakage between the measuring head lands and the glass plate shall not exceed 15 mL/min (approximately two Sheffield units) when the gravity loading on the lands and test air pressure conform to test conditions. There is a mutually-dependent relationship between the surface finish of the glass and the measuring lands that must limit the leakage to 15 mL/min.

4.4 An *air flowmeter*, having the capability to measure the range of flow required for the samples to be tested. A range of 0 to 3400 mL/min (0-400 SU) is recommended.

4.5 A *flow restrictor*, designed to give the system a flow/pressure drop relationship as shown in Table 1. This restrictor is located between the regulated air pressure source and the annular area between the lands. It is the total flow restriction from the regulated air pressure source to the pressure zone in the annular rings that create the flow/pressure drop relationship listed in Table 1.

4.6 A *regulated air supply*, to supply air to the system upstream of the flowmeter and the flow restrictor. In the instruments that utilize variable area flowmeters with air bleeds for calibration, this supply shall be regulated to $10.34 \pm 0.2 \text{ kPa}$ ($1.50 \pm 0.03 \text{ psig}$). In the instruments that utilize mass flowmeters with no air bleeds, this supply shall be regulated to $9.85 \pm 0.2 \text{ kPa}$ ($1.43 \pm 0.03 \text{ psig}$), as this is the pressure that is measured downstream of the typical variable area flowmeters that have been calibrated by using air bleeds to atmosphere. Stages of air pressure regulation upstream of this precision regulator may be necessary in order to maintain the regulated pressure within these specifications.

4.7 A *pressure measuring device*, that has the accuracy to measure the regulated supply pressure within these specifications.

5. Calibration

5.1 Calibrate the instrument according to manufacturer’s instructions. The flow measuring device may be calibrated using electronic mass flowmeters that have calibration curves traceable to the NIST. The relationship between the traditional “Sheffield Unit” and engineering units (mL/min) is shown in Table 2. “Working standards” in the form of calibrated orifices or laminar flow restrictors are available from the manufacturers of the equipment. Each manufacturer publishes instructions for using their respective calibration equipment.

5.2 Perform air pressure calibration with instruments calibrated to the NIST. A “working standard” for pressure measurement may be in the form of either a mercury manometer or an electronic pressure measuring instrument.

5.3 Check the condition of the instrument by lowering the gauge head gently onto the glass plate with no specimen in place. The air flow reading shall not exceed 15 mL/min (approximately 2 SU).

6. Sampling

Select samples in accordance with TAPPI T 400 “Sampling and Accepting a Single Lot of Paper, Paperboard, Fiberboard or Related Product.”

7. Test specimens

7.1 From each test unit of the sample select at least 10 specimens with a minimum size of $75 \times 75 \text{ mm}$ ($3 \text{ in.} \times 3 \text{ in.}$). Identify and mark the side tested (wire or felt, etc.).

7.2 If watermarks are present this should be noted in the test report.

8. Conditioning

Precondition, condition, and test the specimens in the atmospheres that are in accordance with TAPPI T 402 “Standard Conditioning and Testing Atmospheres for Paper, Board, Pulp Handsheets and Related Products.”

9. Procedure

9.1 Follow the recommendations of the instrument manufacturer for preparing the instrument for testing. This includes proper calibration of the instrument.

9.2 The glass plate surface and gauging surfaces must be clean. If necessary, wipe the surfaces with a soft lint-free cloth or tissue.

9.3 Raise the gauge head and insert the specimen between the head and the glass plate with the side to be tested facing upwards.

Table 2. Conversion of traditional Sheffield units to engineering units

<i>Tube #3 (SU)</i>	<i>Flow (mL/min)</i>	<i>Tube #2 (SU)</i>	<i>Flow (mL/min)</i>	<i>Tube #1 (SU)</i>	<i>Flow (mL/min)</i>
0	0	50	313	160	1342
5	35	60	404	180	1509
10	70	70	495	200	1676
15	104	80	585	220	1843
20	139	90	676	240	2010
25	174	100	767	260	2178
30	209	110	858	280	2345
35	244	120	949	300	2512
40	278	130	1039	320	2679
45	313	140	1130	340	2846
50	348	150	1221	360	3014
55	383	160	1312	380	3181
60	418	170	1403	400	3348
		180	1493		
		190	1584		

Sheffield Tube #	Recommended range Sheffield units (SU)	Conversion to engineering units (mL/minute)
3	0 - 56	mL/min = 6.96 (SU)
2	56 - 170	mL/min = 9.08 (SU) - 141
1	170 - 400	mL/min = 8.36 (SU) + 4

mL/min = milliliters per minute referenced to 760 mm Hg and 21°C

9.4 Lower the test head gently onto the specimen at a speed that will not damage the surface and affect the measurement reading. A reasonable speed for the descent of the dead weight (not to be confused with the handle rotational speed) is 0.5 cm/sec (this process is automated in many pieces of equipment).

9.5 When reading variable area flowmeters, record the position of the top of the float when the float reaches a position of relative stability on the scale. Select the appropriate flowmeter column that allows a reading that falls between the two calibration marks inscribed on the scale; i.e., do not record values that are above the highest calibration marks on two lower-flow columns, or those values that are below the lowest calibration marks on the two higher-flow columns. When electronic mass flowmeters are used, follow the manufacturer’s instructions.

9.6 Test a total of 10 specimens, one reading on each specimen. Note the side tested.

10. Report

10.1 Report the average of the 10 readings in Sheffield Units (SU), or mL/min. A conversion scale is available in Table 2 that shows the relationship between the traditional “Sheffield Unit” and engineering units. The values in Table 2 were obtained from a survey of 12 instruments.

10.2 Report the side of the specimen tested (wire or felt, top or bottom, etc.).

11. Precision

11.1 Repeatability and reproducibility are estimates of the maximum difference (at 95% confidence) that should be expected when comparing test results for materials similar to those described below under similar test conditions. These estimates may not be valid for different materials, testing ranges, and testing conditions.

11.2 Repeatability (within a laboratory) = 5%.

11.3 Reproducibility (between laboratories) = 13%.

11.4 These estimates of repeatability and reproducibility listed above are based on data from the CTS Paper & Paperboard Interlaboratory Program and Containerboard Interlaboratory Testing Program. The testing was conducted between 2018 and 2020. The precision estimates are based on the average of 10 determinations and 1 test result per lab for each round of testing. Only laboratories that reported performing the testing in accordance with this method and adhering to standard conditioning atmospheres were included in the calculations.

Table 3. Precision Results Table

Material	Mean	Repeatability r and %r	Reproducibility R and %R	Labs Included
50 lbs. Offset	115.1	6.59 5.7 %	15.45 13.4 %	46
24 lbs. Bond	151.2	11.64 7.7 %	20.05 13.3 %	50
70 lbs. Offset	90.1	4.14 4.6 %	16.92 18.8 %	53
42 lb. Linerboard	362.5	10.46 1.9 %	9.93 5.8 %	12

Results listed in Sheffield Units.

11.5 The user of this data is advised that it is based on actual mill and laboratory testing. There is no knowledge of the exact degree to which the referenced test method was employed. The precision quoted provides an estimate of typical variation in test results which may be encountered when this method is routinely used.

12. Keywords

Print quality, Roughness, Sheffield smoothness, Smoothness, Surface roughness.

13. Additional Information

13.1 Effective date of issue: To be assigned.

13.2 After the introduction of instruments that utilize electronic mass flowmeters with digital readouts, it became apparent in the CTS Collaborative Reference Program (GL17 through GL24) that there was a bi-modal response when comparing the newer technology to the instruments that utilized variable area flowmeters. For the range from 50 to 140 Sheffield Units, the correlation was calculated to be:

$$Y = 3.38 + 1.06 X$$

Where

Y = average for instruments utilizing variable area flowmeters.

X = average for instruments that utilize electronic mass flowmeters with digital readouts.

There is insufficient data to determine if the offset is related to the manufacturing tolerances of the measuring head land widths, or if the surveys are influenced by a group of relatively new digital instruments being compared with variable area flowmeter instruments of mixed age and maintenance.

13.3 The only changes made in the 2008 version were editorial.

13.4 The only changes made in the 2016 version were editorial.

13.5 The changes made in the 2021 version were editorial and also included more recent data to update the precision statement.

Reference

1. Hagerty, G. A. And Walkinshaw, J. W., "The Sheffield Unit - Update to Today's Technology," *Tappi Journal* 71(1): 101 (1988).

Your comments and suggestions on this procedure are earnestly requested and should be sent to the TAPPI Standards Department.

