CMHC SCHL
Helping to house Canadians

Canada

AIR PERMEANCE OF BUILDING MATERIALS

Prepared for: Mr. Jacques Rousseau
Senior Project Manager
Canada Mortgage and Housing Corporation
682 Montreal Road
Ottawa, Ontario
K1A 0P7

Submitted by: AIR-INS Inc.
2217 Guenette
St-Laurent, Quebec
H4R 2E9
Tel: (514) 331-2710
Fax: (514) 331-6671

17 June 1988

AIR PERMEANCE OF BUILDING MATERIALS

Prepared for: Mr. Jacques Rousseau
Senior Project Manager
Canada Mortgage and Housing Corp.
682 Montreal Road
Ottawa, Ontario
KIA OP7

Submitted by: AIR-INS Inc.
2217 Guenette
St-Laurent, Que.
H4R 2E9

Tel: (514) 331-2710
Fax: (514) 331-6771

Date of the report: June 17th, 1988

Prepared by:

Doru Bumbaru B.S.

Robert Jutras P. Eng.

Armand Patenaude P. Eng., M.S.

Canada Mortgage and Housing Corporation, the Federal Goverment's housing agency, is responsible for administering the National Housing Act.

This legislation is designed to aid in the improvement of housing and living in Canada. As a result, the Corporation has interests in all aspects of housing and urban growth and development.

Under Part V of this Act, the Government of Canada provides funds to CMHC to conduct research into the social, economic and technical aspects of housing and related fields, and to undertake the publishing and distribution of the results of this research. CMHC therefore has a statutory responsability to make widely available, information which may be useful in the improvement of housing and living conditions.

This publication is one of the many items of information published by CMHC with the assistance of federal funds.

DISCLAIMER

This study was conducted by AIR-INS Inc. for Canada Mortgage and Housing Corporation under part V of the National Housing Act. The analysis, interpretations and recommendations are those of the consultants and do not necessarily reflect the views of Canada Mortgage and Housing Corporation of those divisions of the Corporation that assisted in the study and its publication.

TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

1. MANDATE

The first attribute of a simple or composite material being part of the air barrier system for a building envelope is to offer a low air permeance.

The objectives of this study are:

a) To propose and validate a test method to measure the air permeance of building materials;

b) Using the proposed test method, measure the air permeance of several building materials at various pressure differentials (25 to 100 Pa);

c) To classify the selected building materials using the measured air flow rates per unit area ($L/S\text{-}m^2$).

2. EXECUTIVE SUMMARY:

2.1 BACKGROUND

This CMHC project was undertaken by AIR-INS Inc. with assistance from the Institute of Research in Construction (IRC) to propose and validate a test method to determine the air permeance of building materials. Validation of test results was conducted on orifice plates and on building materials. Using the proposed test method, a total of 126 specimens from 36 building materials were tested at static pressure differentials varying from 25 to 100 Pa.

2.2 KEY RESULTS

When applied to orifice plates, the validation process clearly shows that Air-Ins Inc. and IRC test results are within 1 to 7 % of each other.Furthermore, best accuracy is reached at pressure differentials of 75 to 100 Pa.

For building materials, the validation process shows that test results from IRC and Air-Ins Inc. are very close to each other.

The application of the test method to the 36 building materials yields the following:

- 12 materials show a non-measurable air flow;
- 9 materials show an air flow rate smaller than 0.05 L/S-m^2 at a pressure differential of 75 Pa;
- 1 material shows an air flow rate between 0.1 and 0.15 L/S-m^2 at a pressure differential of 75 Pa;
- 14 materials show an air flow rate higher than 0.15 L/S-m^2 at a pressure differential of 75 Pa;

The results also show that:

- inhomogeneity does exist within a given board;
- inhomogeneity does exist from one board to another for a specific material;
- the air flow regime through building materials having and air flow rate smaller than 0.15 L/S-m^2 is mainly laminar.

2.3 CONCLUSIONS

The test method developed by the present study has been demonstrated by the validation process to be in close agreement with the test method developed by IRC.

The test method has been shown to be capable of measuring air flow rates of 0.005 L/S-m^2 to 30 L/S-m^2 with reasonable accuracies.

The study confirmed that at pressure differentials of 25 to 100 Pa, the air flow regime through building materials is mainly laminar.

3. INTRODUCTION

The need for improved air tightness of the building envelope has now become an accepted fact of life. Air infiltration and exfiltration through the building envelope has been blamed for the premature failure of many new wall systems.

Eventhough subsection 5.3.1 of the 1985 National Building Code recognizes the fact that "the assembly shall be designed to have an effective barrier to air exfiltration and infiltration", there are no specific permissible air leakage rates given in the Building Code.

To achieve air tighness of a building envelope, an air barrier system should be designed to perform the unique function of resisting air infiltration and/or air exfiltration. To accomplish this, the system must have the following attributes: continuity, strength, air impermeability and durability.

Among the above aforementionned attributes, the air impermeability of building materials used to build the air barrier system is certainly the first characteristic to evaluate in order to set limitations.

4. THEORY

4.1 MODES OF AIR FLOW

A unidirectional steady flow of air through a permeable material is represented in Figure 1.

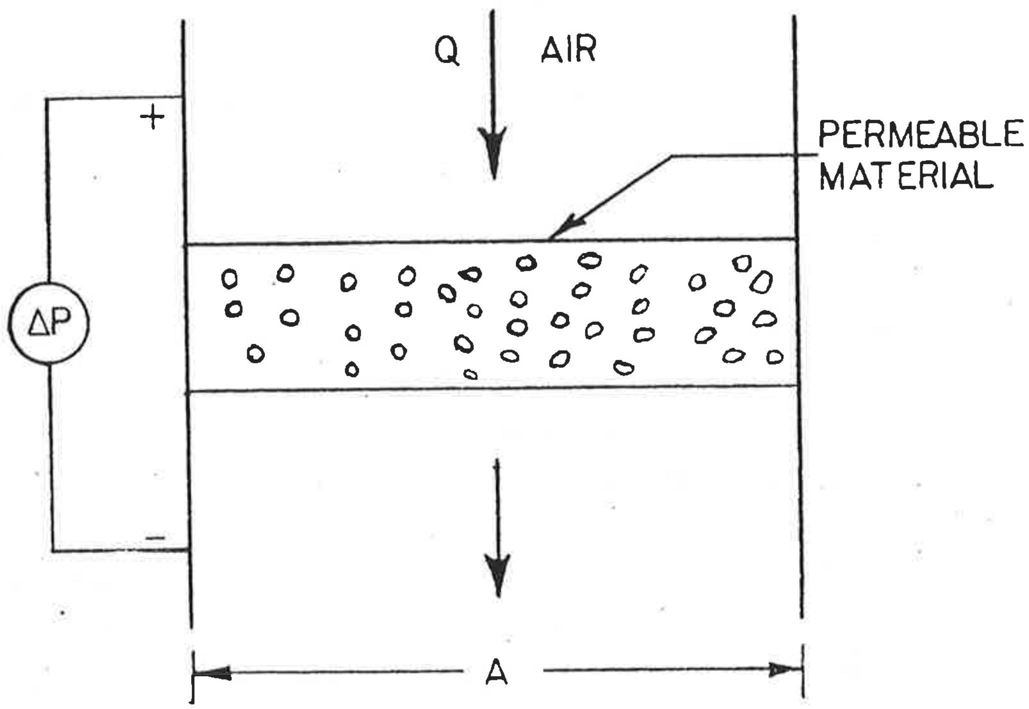


FIGURE 1: FLOW OF AIR THROUGH A PERMEABLE MATERIAL

The mode of air flow may be either laminar, turbulent or a combination of both. The criterion for the breakdown of laminar motion and the transition to turbulent motion is a dimensionless quantity which bears the name of Reynolds number.

4.1.1 LAMINAR FLOW

For laminar motion of air through a permeable material, the rate of air flow can be expressed by:

$$Q = K\,A(\Delta P)$$

where:

Q = Volumetric flow rate of air (L/s).

K = Constant dependant on the intrinsic air permeability of the material, its thickness and the dynamic viscosity of air ($L/s\text{-}m^2\text{-}Pa$).

A = Normal cross - sectional area of the material (m^2).

ΔP = Static air pressure differential across the material (Pa).

4.1.2 TURBULENT FLOW

For turbulent motion of air through a permeable material, the rate of air flow can be expressed by:

$$Q = K\,A\,(\Delta P)^{1/2}$$

where:

Q = Volumetric flow rate of air (L/s).

K = Variable dependant on the intrinsic air permeability of the material, its thickness and the dynamic viscosity of air ($L/s\text{-}m^2\text{-}Pa^{1/2}$).

A = Normal cross-sectional area of the material (m^2).

ΔP = Static air pressure differential across the material (Pa).

4.1.3. LAMINAR + TURBULENT FLOW

Building materials are heterogeneous by nature. The mode of air flow through a material may change from laminar to turbulent at several locations within it. Furthermore, entrance and exit effects may also be different from the mode of air flow existing within the material. Therefore, in order to cover all possibilities, the rate of air flow may be expressed by:

$$Q = K\ A\ (\Delta P)^n$$

where:

- Q = Volumetric flow rate of air (L/s).
- K = Variable dependant on the intrinsic air permeability of the material, its thickness and the dynamic viscosity of air ($L/s\text{-}m^2\text{-}Pa^n$).
- A = Normal cross-sectional area of the material (m^2).
- ΔP = Static air pressure differential across the material (Pa).
- $0.5 < n < 1.0$

A graphical representation of each mode of air flow through a permeable material is shown on Figure 2.

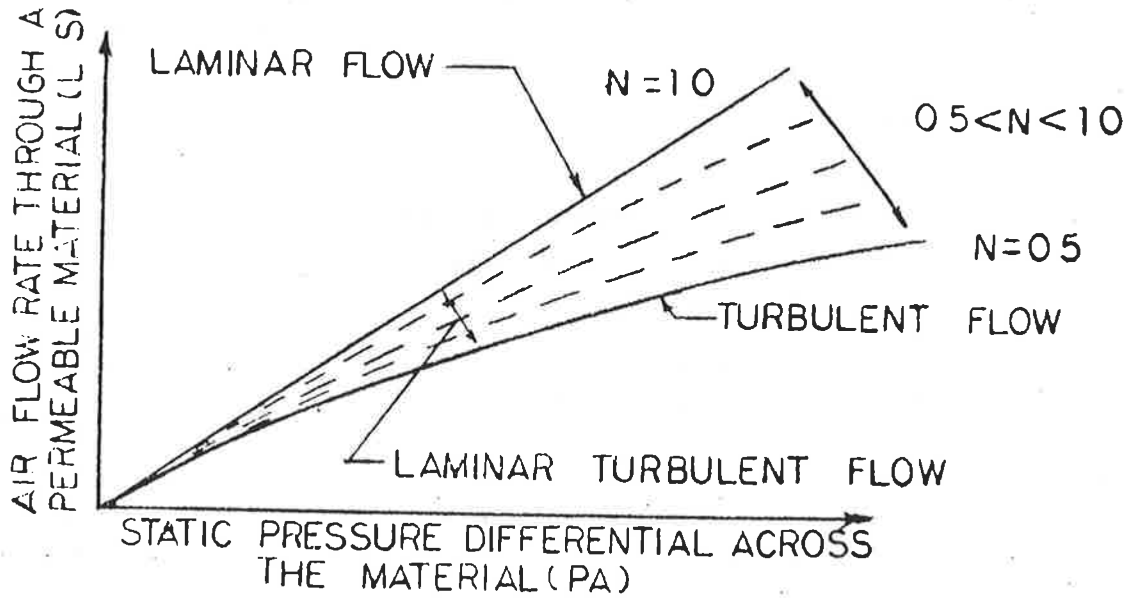


FIGURE 2: MODES OF AIR FLOW

4.2 AIR PERMEANCE OF BUILDING MATERIALS

The air permeance of a building material is defined as the rate of air flow (L/s), per unit area (m^2) and, per unit static pressure differential (Pa). It is represented by the value of "P" in the following equation:

$$\text{AIR PERMEANCE} = P = \frac{Q}{A\,(\Delta P)}$$

Using the above expression, one can notice that air permeance of a material will give a constant for laminar flow and will depend on the static pressure differential for turbulent and combined flows.

The air permeance units can be reduced further by substituting "litres" into "m^3". The following expression shows the conversion.

$$P = \frac{L}{s\text{-}m^2\text{-}Pa} = \frac{m}{s\text{-}Pa} \times 10^3$$

4.3 RESISTANCE TO AIR FLOW PROVIDED BY BUIDING MATERIALS

The resistance to air flow provided by a building material (R) is the reciprocal of the air permeance.

$$R = \frac{1}{P}$$

Units are: $\frac{(s - Pa)}{m}$ or $\frac{(s\text{-}m2\text{-}Pa)}{L}$

4.4 EQUIVALENT LEAKAGE AREA (ELA)

As per CAN3-149.10-M85 Standard: "Determination of the airtightness of building envelopes by fan depressurization method", the equivalent leakage area is defined herein as: the area of a single sharp-edged orifice which would yield the same rate of air flow as the combined leakage openings in the permeable material under investigation, when both are subjected to a static pressure differential of 1 Pa.

The equivalent leakage area can be calculated by the following equation:

$$ELA = 0.001157\sqrt{\rho_r}\ C_r\ 10^{n-0.5}$$

where:

ELA = Equivalent leakage area (m^2)

ρ_r = Air density at reference conditions.
For $T_r = 20^oC$ and $P_r = 101.325$ kPa,
the density of air is $\rho_r = 1.204097\ kg/m^3$.

C_r = KA = Air flow rate that would occur through the specific permeable material at reference ambient conditions and at P = 1 Pa and is in units of L/s - Pa^n.

n = The exponent related to the specific permeable material under investigation.

Figure 3 shows a graphical representation of ELA for a given permeable material.

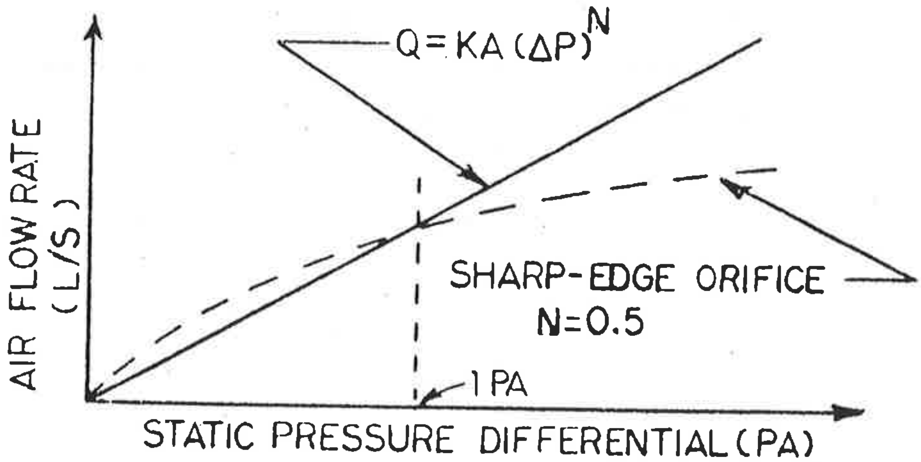


FIGURE 3: AIR FLOW THROUGH A SHARP-EDGED ORIFICE VERSUS A PERMEABLE MATERIAL

4.5 EQUIVALENT ORIFICE DIAMETER

The equivalent orifice diameter is defined as the diameter of a sharp-edged orifice showing the same cross-sectional area as the ELA.

The equivalent orifice diameter can be calculated by the following equation:

$$\text{Dia. ELA} = \sqrt{\frac{4.\text{ELA}}{\pi}} \times 10^{3}$$

where:

Dia.ELA = Equivalent orifice diameter (mm)

ELA = Equivalent leakage area (m^2) (as defined in 4.4)

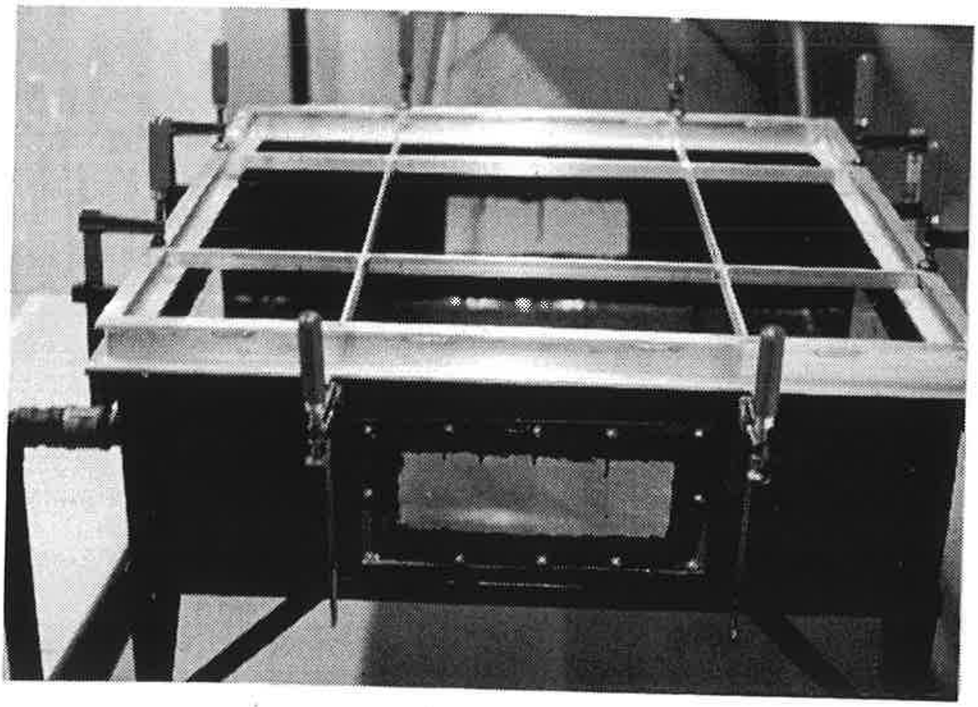
5. TEST APPARATUS

The different components of the test apparatus are shown in Figure 4.

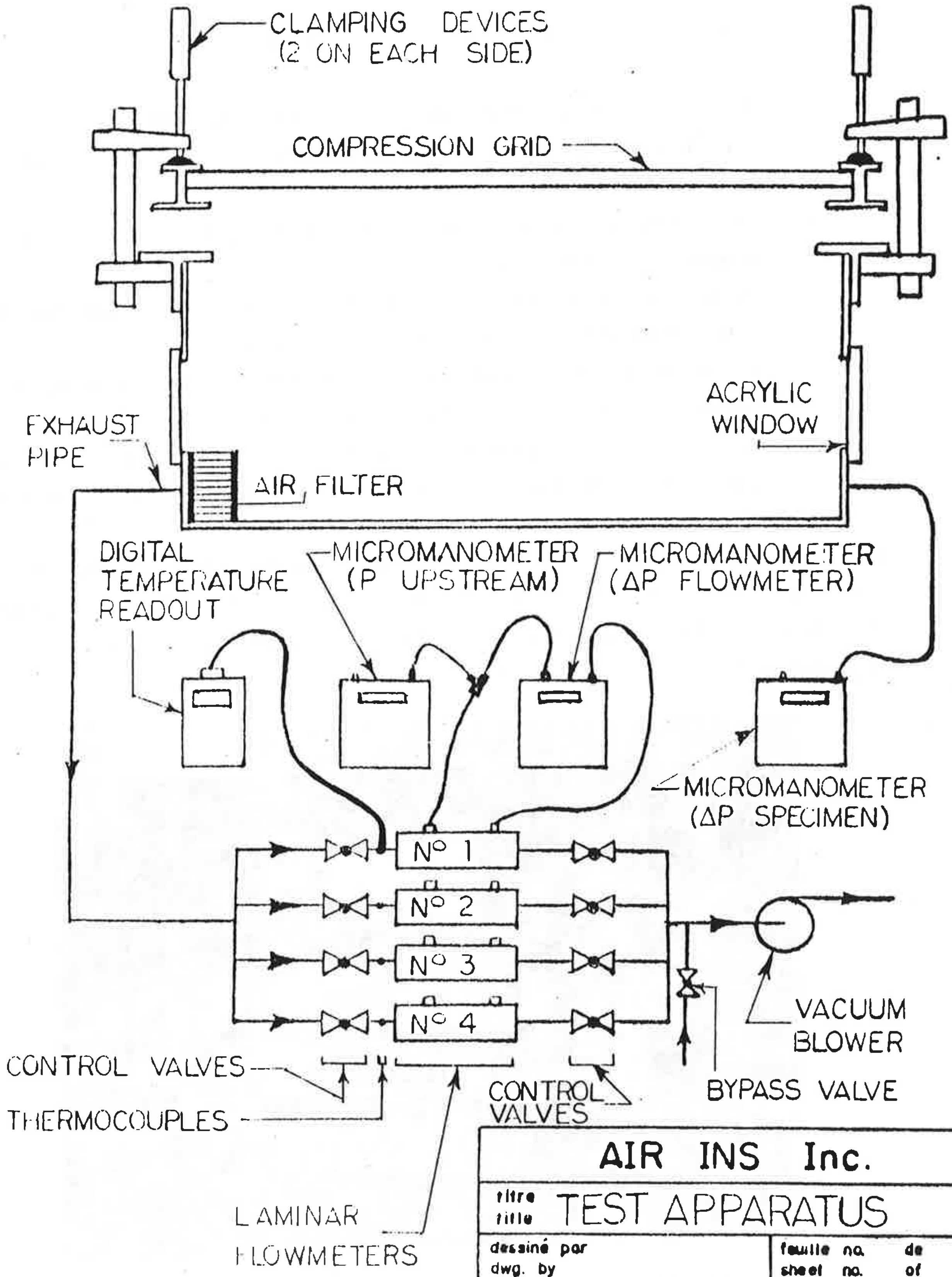
The system includes:

- A test chamber on which the specimen is installed;
- Flow measuring devices;
- Pressure measuring devices;
- Flow control devices (ball valves);
- A vacuum blower creating a depression inside the test chamber.

5.1 TEST CHAMBER (see photograph no. 1):



Photograph 1: TEST CHAMBER



AIR INS Inc.		
titre / title	TEST APPARATUS	
dessiné par / dwg. by		feuille no. de / sheet no. of
vérifié par / chk. by		légende no. / mtl. list no.
échelle / scale	date	dessin no. / dwg. no. 4

The different parts of the test chamber are:

- A 1 m x 1 m x 0.32 m chamber on which the specimen rests;
- A compression grid with inside dimensions of 1 m x 1 m that covers the specimen;
- Two clamping devices on each side of the 1 m x 1 m opening to compress the specimen;
- An acrylic window on each side of the chamber to allow observation and verification of the specimen position;
- An exhaust pipe connected to the test chamber leading to flow measuring devices and to the vaccum blower;
- An air filter, placed on the exaust opening to prevent dust or particulate matter from affecting the reading of the measuring devices.

For materials where a 1 m x 1 m specimen is not feasible, an adapter with an opening of 0,609 m x 0,921 m is placed on the 1 m x 1 m opening of the test chamber. This is to allow for testing of a smaller specimen (see photograph 2).

Photograph 2: TEST CHAMBER WITH THE SPECIAL ADAPTER

5.2 FLOW MEASURING DEVICES

Since the expected air permeance of tested specimens varies to a great extent for different materials, four Meriam laminar flowmeters were used to measure the air flow.

The flowmeters used are:

- Flowmeter No.1: Meriam Model 50MJ10-1/2 Type 14

  Range: $0 - 3.78 \times 10^{-5}\ m^3/s$

- Flowmeter No.2: Meriam Model 50MJ10-1/2 Type 13

  Range: $0 - 9.44 \times 10^{-5}\ m^3/s$

- Flowmeter No.3: Meriam Model 50MH10-1-NT

  Range: $0 - 377 \times 10^{-5}\ m^3/s$

- Flowmeter No.4: Meriam Model 50MW20-2

  Range: $0 - 1880 \times 10^{-5}\ m^3/s$

5.3 PRESSURE MEASURING DEVICES

Pressure measuring devices were required to measure the air flow rate and the static pressure differential across the specimen.

The evaluation of the air flow rate through the specimen requires the following pressure measurements:

- ΔP laminar flowmeter
- P upstream
- Barometric pressure

ΔP laminar flowmeter and P upstream were measured by micromanometers.

ΔP laminar flowmeter: Model MP6KD
Scale: 0 - 19.99 in H_2O
"Air Instrument Resources Ltd"

P upstream : Model MP6KD
Scale: 0 - 19.99 in H_2O
"Air Instrument Resources Ltd"

Barometric pressure data were collected from Environment Canada (Montreal weather office).

The static pressure differential across the specimen (negative pressure inside the test chamber versus reference pressure from the laboratory) was measured with a micromanometer:

ΔP specimen : Model MP3KDS
Scale: 0 - 19.99 in H_2O
"Air Instrument Resources Ltd"

5.4 TEMPERATURE MEASURING DEVICES

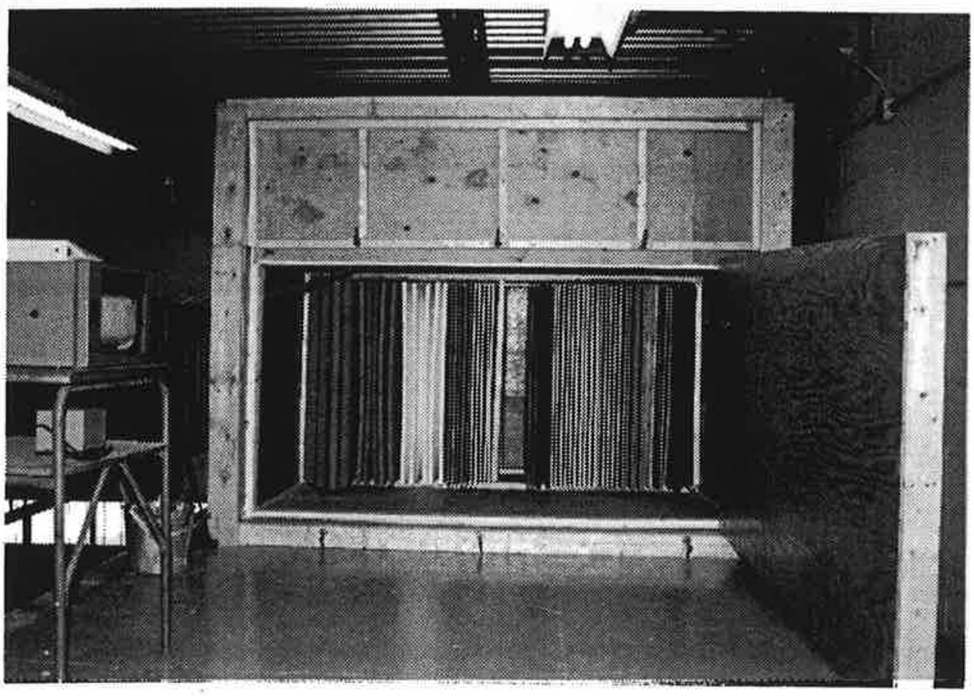
To determine the actual air flow rate through the flowmeter, a temperature measurement is required on the upstream side of the flow measuring device.

The temperature is obtained using a chromel-alumel thermocouple coupled to a digital readout.

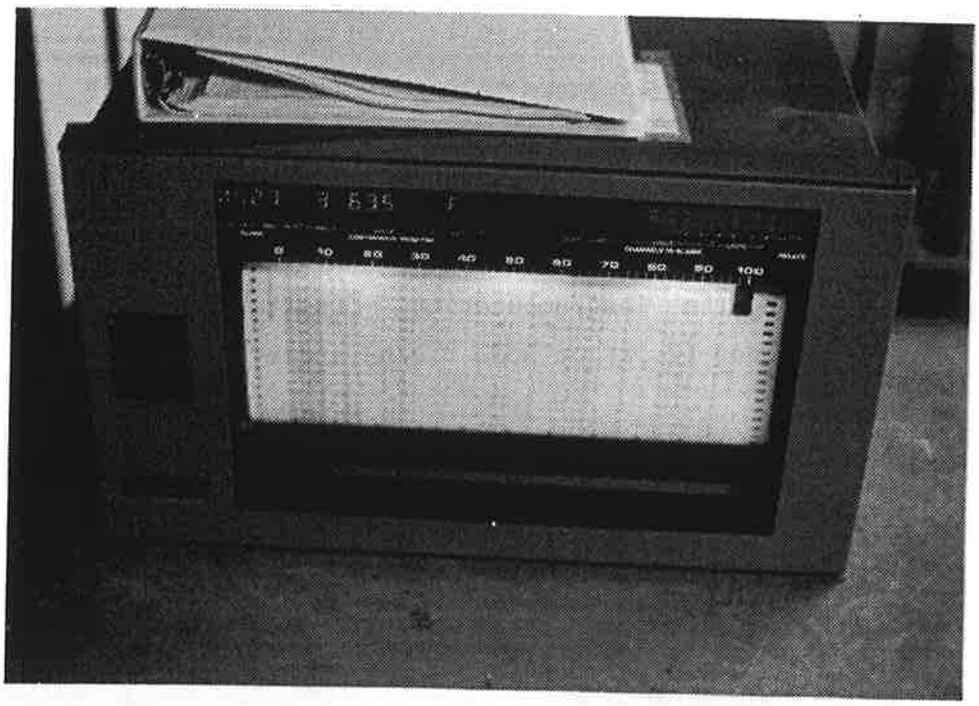
6. TEST METHOD

6.1 CONDITIONING

Prior to testing, all samples were conditioned for a minimum period of one week at a temperature of 21± 1 °C, while relative humidity was maintained at 39± 1%. Photographs no. 3 and 4 show the conditioning chamber and the instrumentation. Conditioning is accomplished by an air-conditioner (2.3kW or 8000 BTU/h) and a dehumidifier.



Photograph no. 3: CONDITIONING CHAMBER



Photograph no. 4: DATA ACQUISITION SYSTEM
(Dry-bulb and wet-bulb
temperature measurements)

6.2 PREPARATION OF TEST SPECIMEN

In order to cover all possibilities, preparation of test specimen differed from one material to another. The main criteria of selection were rigidity and dimensions (length x width x thickness).

6.2.1 RIGID MATERIALS

A) SHEETS EXCEEDING 1M X 1M

Figure no. 5 shows the preparation for a typical rigid material whose dimensions exceed the 1m x 1m cross-sectional area.

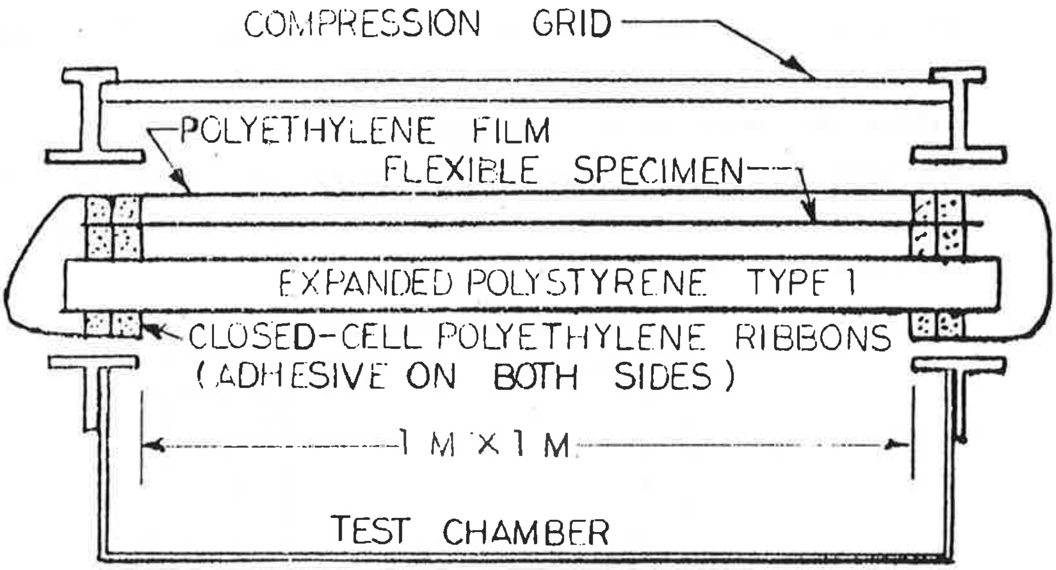


Figure no. 5: Preparation of test specimen for rigid materials.

Preparation consists of the following operations:

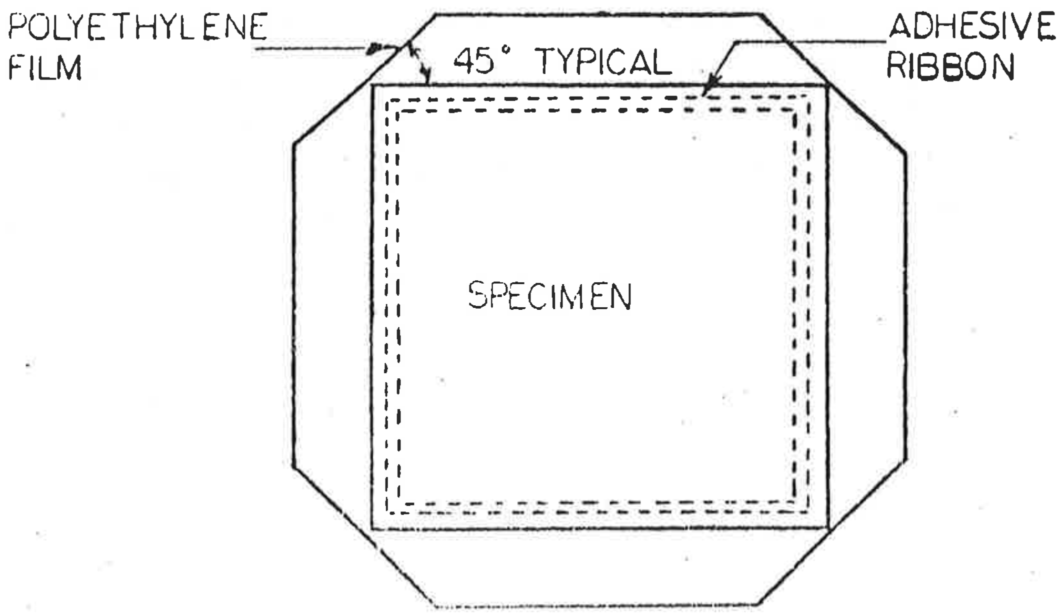
a) using a plywood pattern over the specimen, apply a closed-cell compressible adhesive ribbon (polyethylene - 12 mm width x 6 mm height) around the entire perimeter of the area under investigation (1 m x 1 m);

b) seal corner junctions of the ribbon;

c) cut a polyethylene film (6 mil.) to 1400 mm x 1400 mm;

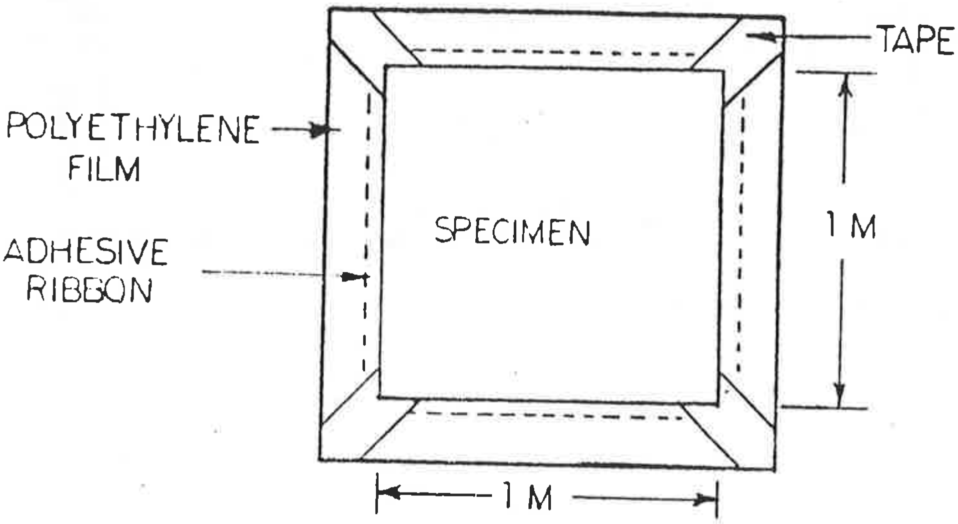
d) upon removal of the protective paper over the ribbon, cover the specimen with the polyethylene film;

e) cut the polyethylene film at each corner as per the following sketch;



f) apply a second closed-cell adhesive ribbon to the underside of the specimen (it should be applied directly under the first adhesive ribbon) and seal corner junctions;

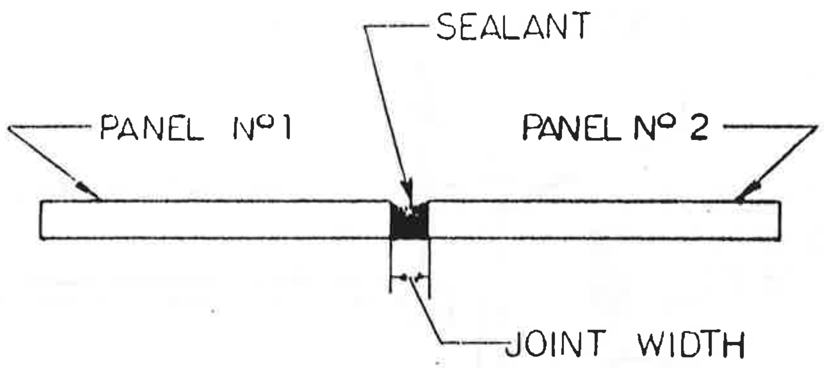
g) upon removal of the protective paper over the ribbon, fold and tape each corner of the film to ensure complete airtightness as per the following sketch;



h) from the interior line of the adhesive ribbon cut all the exceeding polyethylene film.

B) <u>SHEETS WITH ONE DIMENSION SMALLER THAN 1 METER</u>

When the basic material dimensions did not allow to cover the test chamber with a single sheet, two or more pieces were used to create a sample of the designed dimensions (ex.: extruded polystyrene). The joint between these sheets was performed with silicone sealant and its width was carefully measured so that the exact area of the sample would be known. The following sketch illustrates a typical joint between two panels.



NOTE : PROTECT TOP AND BOTTOM SURFACES WHILE APPLYING SEALANT

In some cases, smaller samples were made and a special adapter was used. This special adapter was designed to provide a free area of 0.609m x 0.921m. Figure no. 6 and photograph no. 5 show the adapter construction. The above dimensions were selected on the basis that the new opening would fulfill all the requirements applicable to rigid and flexible materials (except for planks).

6.2.2 FLEXIBLE MATERIALS

Due to their lack of rigidity, flexible materials had to be tested over a rigid support having an air permeance much greater than the test specimen. To perform this task, expanded polystyrene type 1 (material no. 29) was chosen due to its high permeance.

A) FLEXIBLE SHEETS EXCEEDING 1M X 1M

Figure no. 7 shows the preparation for a typical flexible material whose dimensions exceed the 1m x 1m cross-sectional area.

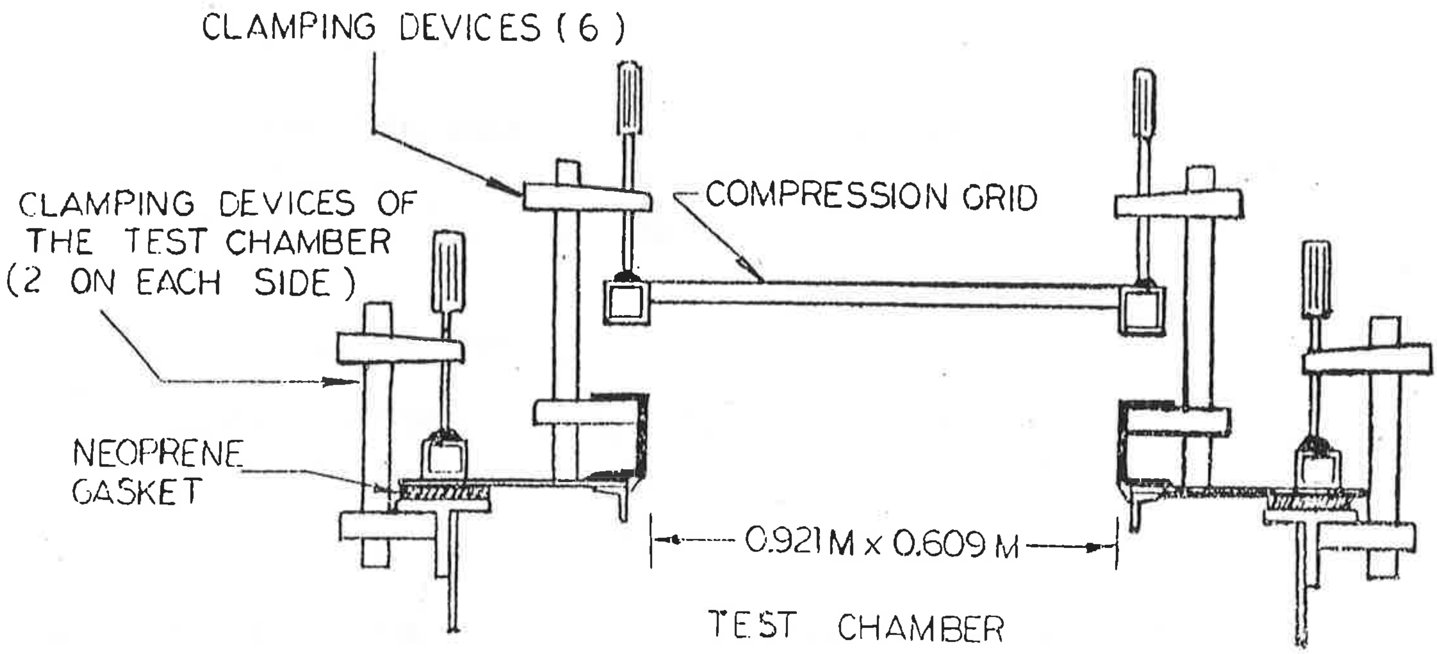
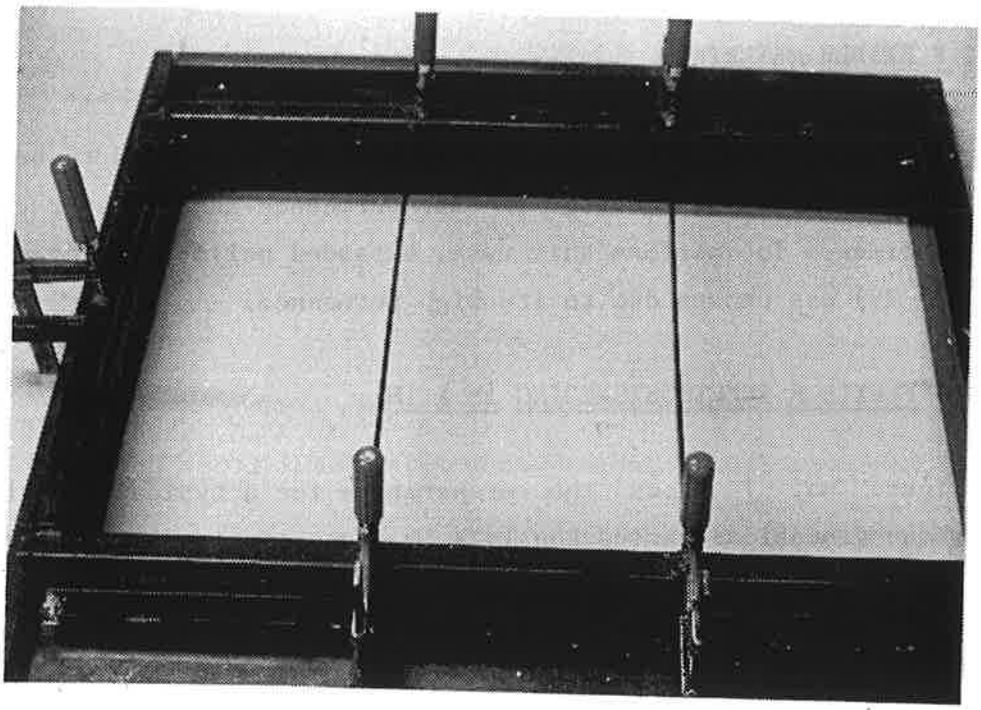


Figure no. 6: ADAPTER DESIGN



Photograph no. 5: ADAPTER

Preparation consists of the following operations:

a) using a plywood pattern over the support material apply a closed-cell compressible adhesive ribbon (polyethylene 12mm width x 6mm height) around the entire perimeter of the area under investigation (1m x 1m);

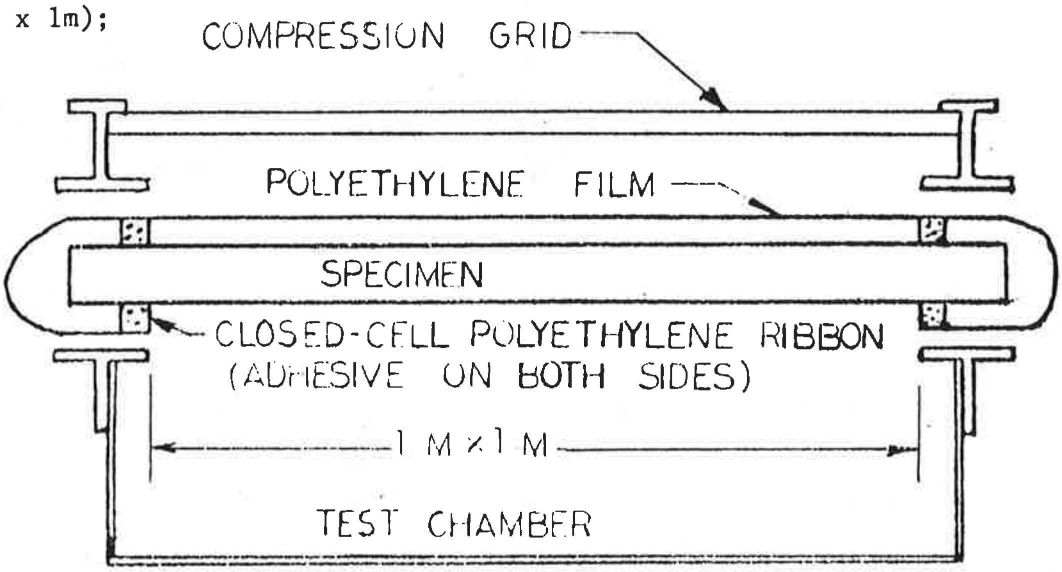


Figure no. 7: Preparation of specimen (flexible material)

b) apply a second closed-cell compressible adhesive ribbon on the perimeter of the first ribbon (see a));

c) seal corner junctions of the ribbons;

d) cut the flexible material to 1100 mm x 1100 mm;

e) upon removal of the protective paper over the ribbon, install the specimen over the base material;

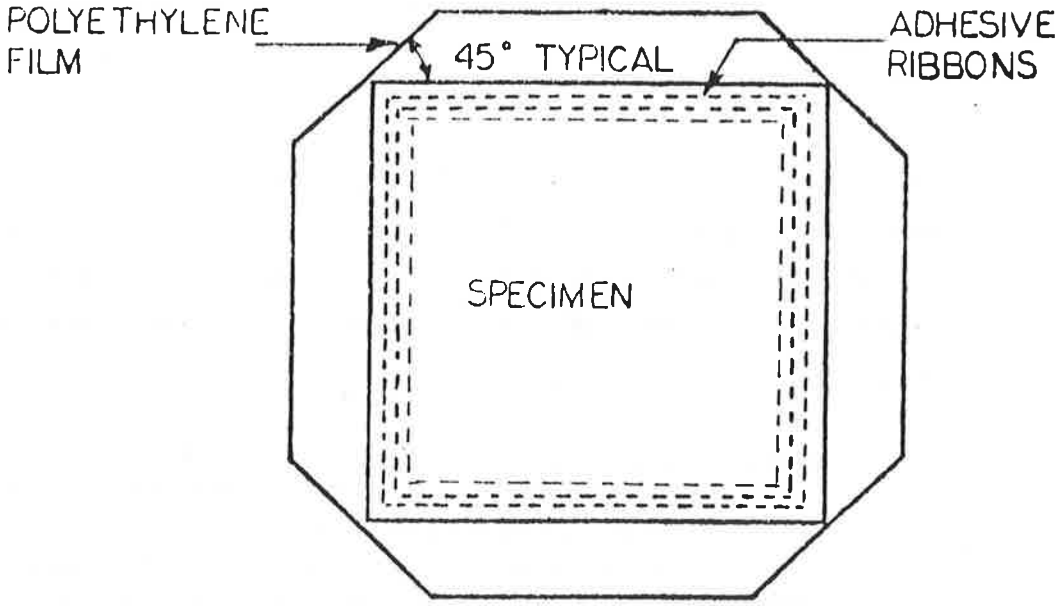
f) apply a closed-cell adhesive ribbon over the specimen, it should be applied directly over the first ribbon (see a)) and apply a second ribbon on its perimeter;

g) seal corner junctions of the ribbons;

h) cut a polyethylene film (6 mils) to 1400 mm x 1400 mm;

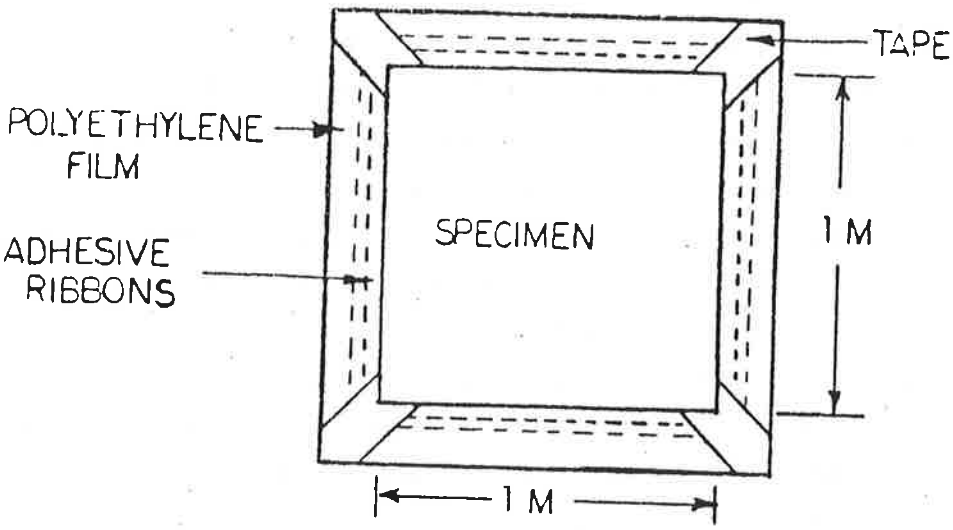
i) upon removal of the protective paper over the ribbon, cover the specimen with the polyethylene film;

j) cut the polyethylene film at each corner as per the following sketch;



k) apply two closed-cell adhesive ribbons to the underside of the specimen; they should be applied directly under the top adhesive ribbons (see a)) and seal corner junctions;

l) upon removal of the protective paper over the ribbon, fold and tape each corner of the film to ensure complete airtightness as per the following sketch;



m) from the interior line of the adhesive ribbon cut all the exceeding polyethylene film.

B) <u>FLEXIBLE SHEETS WITH ONE DIMENSION SMALLER THAN 1 METER</u>

When the basic material dimensions did not allow to cover the test chamber with a single sheet, smaller sample were made and the special adapter was used (see Figure no. 6 and photograph no. 5).

6.2.3 LOOSE MATERIALS

Figure no. 8 shows the preparation for a typical loose material specimen.

Preparation consists of the following operations:

a) install a wood frame with inside dimensions of 1m x 1m over the support material (expanded polystyrene type 1);

b) seal the perimeter of the frame on the support material and seal all corners;

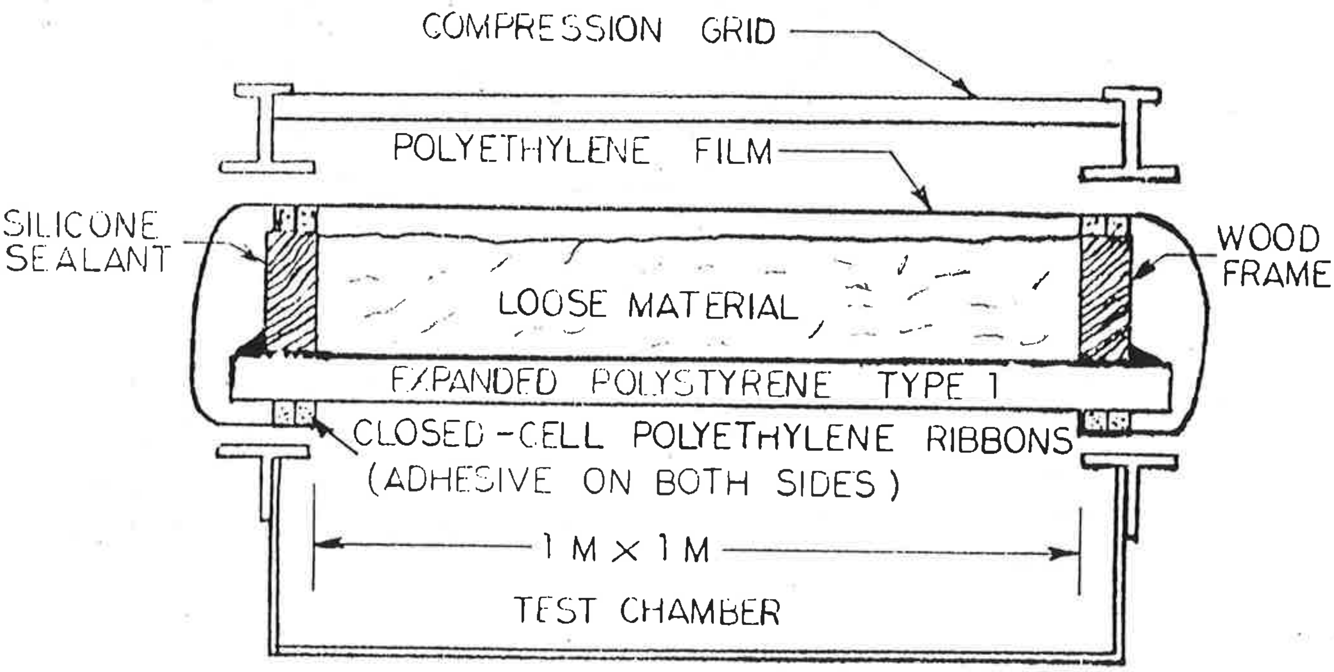


Figure No. 8: Preparation of test specimen (loose material)

c) apply a closed-cell compressible adhesive ribbon to the perimeter of the wood frame;

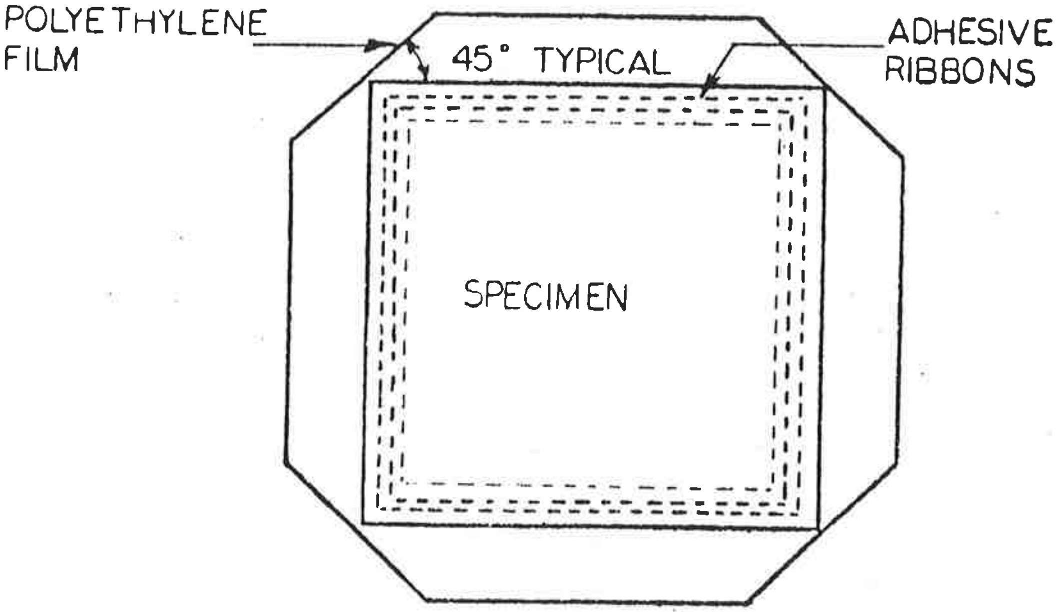
d) seal corner junctions of the ribbon;

e) put the loose material over the support material inside the frame;

f) cut a polyethylene film (6 mils) to 1700mm x 1700mm;

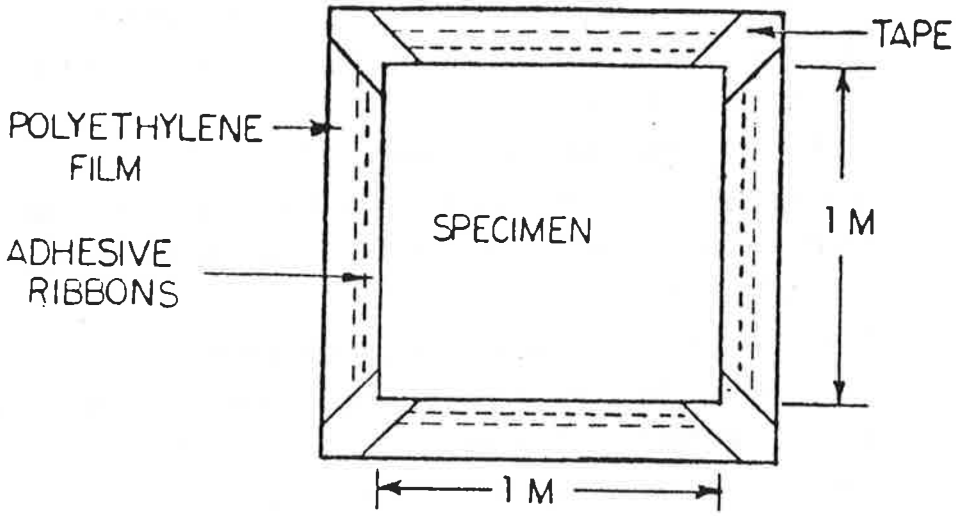
g) upon removal of the protective paper over the ribbon, cover the specimen with the polyethylene film;

h) cut the polyethylene film at each corner as per the following sketch;



i) apply a closed-cell adhesive ribbon to the underside of the specimen, it should be applied directly under the 1m x 1m frame;

j) upon removal of the protective paper over the ribbon, fold and tape each corner of the film to ensure complete airtightness as per the following sketch;



k) from the interior line of the adhesive ribbon cut all the exceeding polyethylene film.

6.3 TEST SEQUENCE

6.3.1 RIGID MATERIALS

a) Install the specimen on the test chamber.
b) Install the compression grid over the specimen.
c) Check through the window if the specimen is properly placed.
d) Compress the specimen.
e) Measure the system leakage (test chamber + the junction of the specimen and the test chamber) at various static pressure differentials (ΔP), near 25, 50, 75 and 100 Pa and, correct the air flow rate values to STP ($T = 20^{o}C$ and $P = 101.325$ kPa).
f) Cut the top section of the polyethylene film.
g) Measure the total leakage (system + specimen) at various static pressure differentials (ΔP), near 25, 50, 75 and 100 Pa and, correct the air flow rate values to STP.

6.3.2. FLEXIBLE AND LOOSE MATERIALS

a) Install the specimen on the test chamber.

b) Install the compression grid over the specimen.

c) Check through the window if the specimen is properly placed.

d) Compress the specimen.

e) Measure the system leakage (test chamber + the junction of the specimen and the test chamber) at various static pressure differentials, near 25, 50, 75 and 100 Pa and, correct the air flow rate values to STP.

f) Cut the top section of the polyethylene film.

g) Measure the total leakage (system + specimen + support) at various static pressure differentials (ΔP), near 25, 50, 75 and 100 Pa and, correct the air flow rate values to STP.

h) Cut the flexible material or remove the loose material.

i) Measure the total leakage (system + support) at various static pressure differentials (ΔP), near 25, 50, 75 and 100 Pa and, correct the air flow rate values to STP.

6.4 CALCULATING THE AIR FLOW THROUGH A COMPONENT AT A GIVEN STATIC PRESSURE DIFFERENTIAL

6.4.1 ACTUAL FLOW RATE

To determine the actual air flow rate through a component (specimen or specimen + leakage from test apparatus) requires collecting the following data:

- ΔP across the laminar flow meter;
- P upstream of the laminar flow meter;
- Barometric pressure, and
- T upstream of the laminar flow meter.

Appendix "A" gives a detailed procedure for calculations.

6.4.2 STANDARD FLOW RATE

Using the ideal gas law, the actual air flow rate is converted to standard air flow rate. Standard conditions are defined as: T = 20°C and P = 101.325 kPa.

6.5 CALCULATING THE PERMEANCE (P), RESISTANCE (R) AND "ELA" OF A BUILDING MATERIAL

6.5.1 RIGID MATERIALS

Calculations include the following steps:

1. a) With a polyethylene film (6 mil) over the specimen, measure the air leakage rate (Q_L) from the test chamber at several static pressure differentials (ΔP) near 25, 50, 75 and 100 Pa;

   b) Correct the air leakage rates (Q_L) to STP;

c) Using an equation of the form $Q_L = K_L (\Delta P)^{nL}$ to represent the dependance of Q on ΔP, determine the constants "KL" and "nL" which represent the best fit. Figure no.9 gives a graphical representation of the above operations.

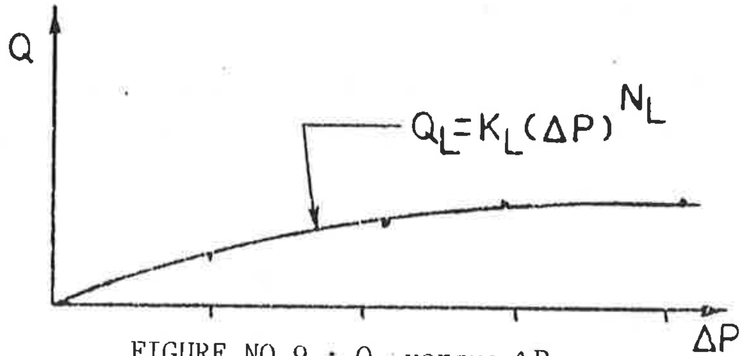


FIGURE NO.9 : Q_L versus ΔP

2. a) Upon removal of the polyethylene film over the specimen, measure the total air leakage rate (Q_{LS}) from the test chamber and from the specimen at several pressure differentials (ΔP) near 25, 50, 75 and 100 Pa;

   b) Correct the air leakage rates (Q_{LS}) to STP;

   c) To determine the air flow rate through a specimen (Q_{Si}) at a given P_i, subtract the calculated value Q_{Li} from Q_{LSi} at the corresponding pressure differential. Repeat the operation for all data pairs.

$$Q_{Si} = Q_{LSi} - Q_{Li} \quad \text{at } \Delta P_i$$

Where: $Q_{Li} = K_L (\Delta P_i)^{nL}$

Figure no. 10 gives a graphical representation of the above operation.

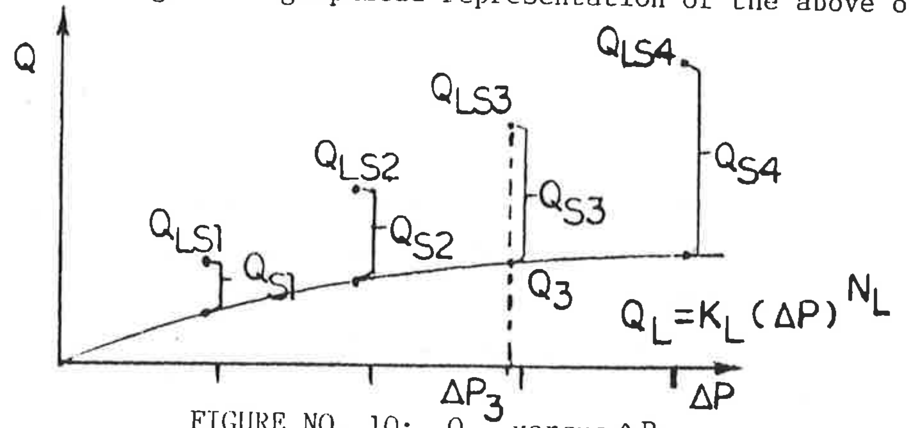


FIGURE NO. 10: Q_{Si} versus ΔP_i

3. Using an equation of the form $Q_S = K_S (\Delta P)^{nSM}$ to represent the dependence of Q_S on P, detrmine the constants "K_S" and "nS" which represent the best fit. Figure no. 11 gives a graphical representation of the above operation.

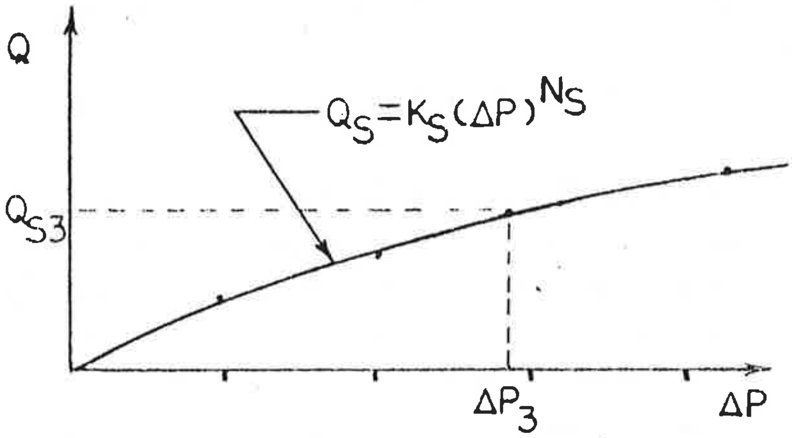


FIGURE NO. 11: Q_S versus ΔP

4. The air permeance (P) of a specimen at a given pressure differential (P), can be calculated by the following equation.

$$P = \frac{Q_S}{A \quad P}$$

Where: P = Permeance (m/Pa-S)

$Q_S = K_S (\Delta P)^{nS}$ (L/S) or (m^3/S)

A = Specimen cross-sectional area (m^2)

P = Pressure differential (Pa)

5. The air resistance (R) of a specimen at a given pressure differential can be found from the reciprocal of P.

$$R = \frac{1}{P}$$

Where: R = Resistance (Pa-S/m)

P = Permeance (m/Pa-S)

6. To obtain the equivalent leakage area (ELA), use the relation given in article 4.4.

$$ELA = 0.001157\sqrt{\rho_r}\ Cr\ 10^{n-0.5}$$

Where: $Cr = KA = K_S A$

7. To obtain the equivalent orifice diameter (Diam. ELA), use the relation in article 4.5.

$$Diam.ELA = \sqrt{\frac{4\ ELA}{\pi}} \times 10^3 \qquad (mm)$$

6.5.2 FLEXIBLE AND LOOSE MATERIALS

Calculations include the following steps:

1. a) With a polyethylene film (6 mil) over the specimen, measure the air leakage rate (Q_L) from the test chamber at several pressure differentials (ΔP) near 25, 50, 75 and 100 Pa;

   b) Correct the air leakage rates (Q_L) to STP;

   c) Using an equation of the form $Q_L = K_L (\Delta P)^{nL}$ to represent the dependance of Q on ΔP, determine the constants "K_L" and "nL" which represent the best fit. Figure no. 9 gives a graphical of the above operations.

2. a) Upon removal of the polyethylene film over the specimen, measure the total air flow rate (Q_{LSM}) from the test chamber (L) and through the specimen (S) and support material (M) at several pressure differentials near 25, 50, 75 and 100 Pa;

   b) Correct the air flow rates (Q_{LSM}) to STP;

   c) To determine the air flow rate (Q_{SMi}) through the support material (M) and specimen (S) at a given P_i, subtract the calculated value Q_{Li} from Q_{LSMi} at the corresponding presure differential. Repeat the operation for all data pairs.

$$Q_{SMi} = Q_{LSMi} - Q_{Li} \quad \text{at} \quad P_i$$

Where:

$$Q_{Li} = K_L (\Delta P_i)^{nL}$$

Figure no. 12 gives a graphical representation of the above operation.

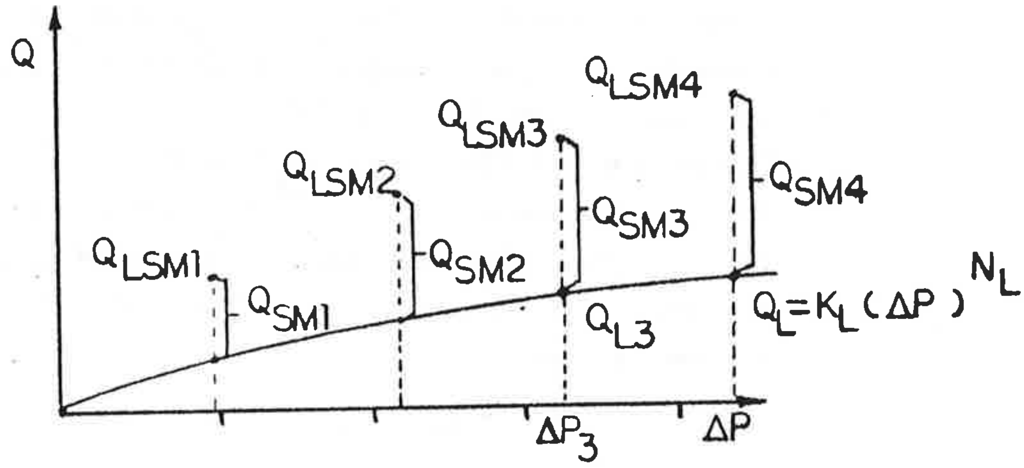


FIGURE NO. 12: Q_{SMi} versus ΔP_i

3. Using an equation of the form $Q_{SM} = K_{SM} (\Delta P)^{nSM}$ to represent the dependence of Q_{SM} on ΔP, determine the constants "K_{SM}" and "nSM" which represent the best fit. Figure no. 13 gives a graphical representation of the above operation.

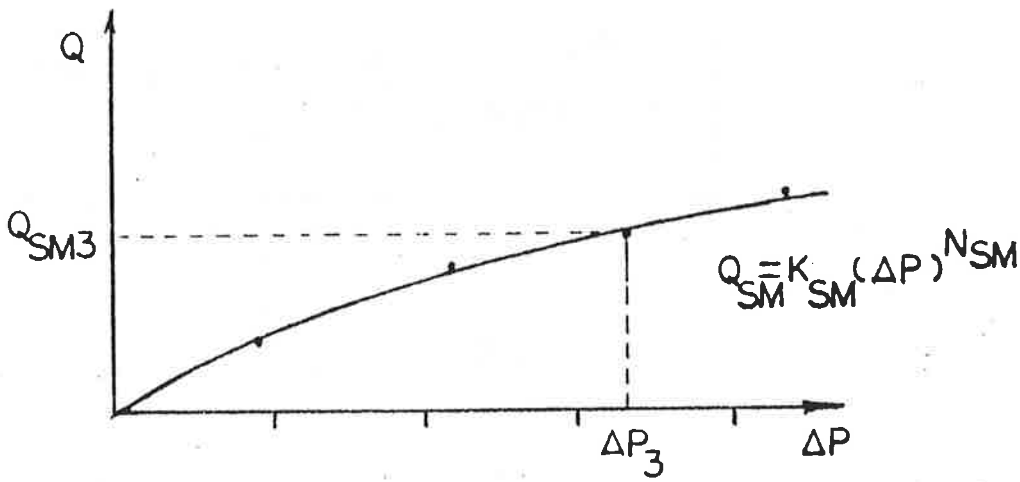


FIGURE NO. 13: Q_{SM} versus ΔP

4. a) Upon removal or cutting of the specimen over the support material, measure the total air flow rate (Q_{LM}) from the test chamber (L) and through the support material (M) at several pressure differentials (ΔP) near 25, 50, 75 and 100 Pa;

   b) Correct the air flow rates (Q_{LM}) to STP;

   c) To determine the air flow rate (Q_{Mi}) through the support material (M) at a given ΔP_i, subtract the calculated value Q_{Li} from Q_{LMi} at the corresponding pressure differential. Repeat the operation for all data pairs.

$$Q_{Mi} = Q_{LMi} - Q_{Li} \quad \text{at } \Delta P_i$$

Where: $$Q_{Li} = K_L \, (\Delta P_i)^{nL}$$

Figure no. 14 gives a graphical representation of the above operation.

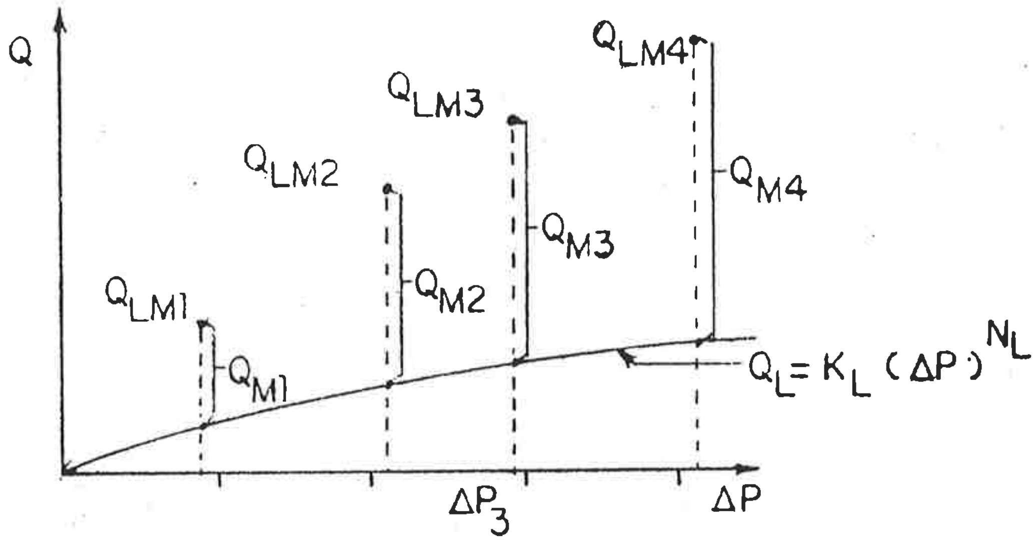
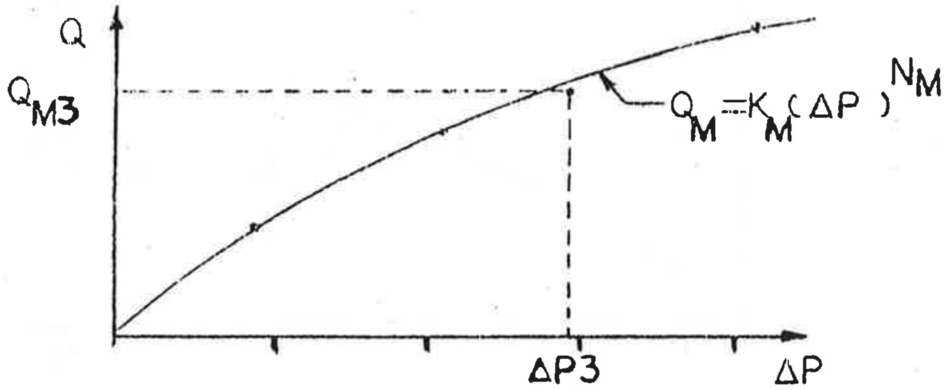


FIGURE NO. 14: Q_{Mi} versus ΔP_i

5. Using an equation of the form $Q_M = K_M (\Delta P)^{nM}$ to represent the dependence of Q_M on ΔP, determine the constants "K_M" and "nSM" which represent the best fit. The following figure gives a graphical representation of the above operation.



6. To determine the pressure drop through the specimen (ΔP_S) at various flow rates, use equations $Q_{SM} = K_{SM} (\Delta P)^{nSM}$ and $Q_M = K_M (\Delta P)^{nM}$ to compute ΔP_S at selected flow rates. Figure no. 15 gives a graphical representation of the above operations.

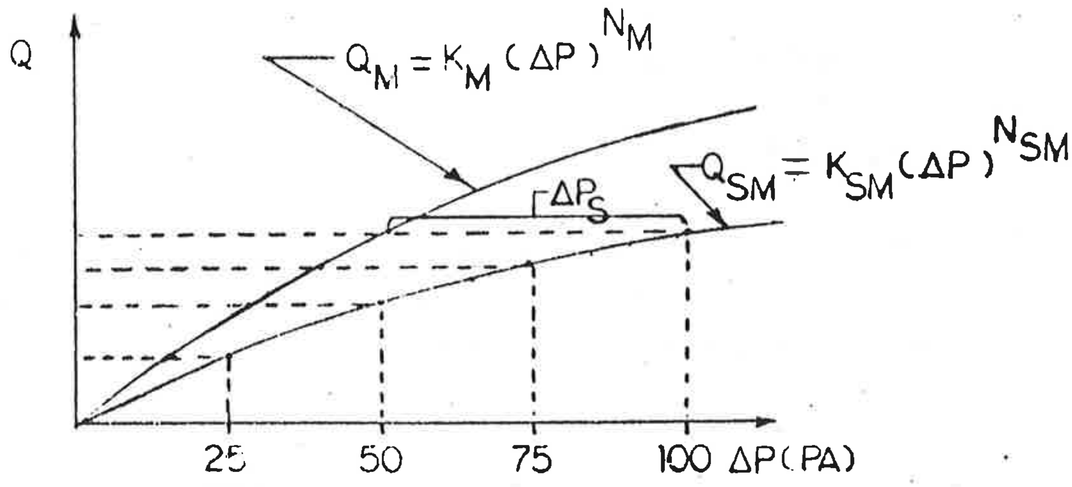


FIGURE NO. 15 : Q versus ΔP

7. Finally, to determine the flow rate through the specimen (Q_S) at various pressure differentials ($\Delta P = \Delta P_S$), use an equation of the form $Q_S = K_S (\Delta P)^{nS}$ to represent the dependence of Q_S on ΔP and determine the constants "K_S" and "nS" which represent the best fit. Figure no. 16 gives a graphical representation of the operation.

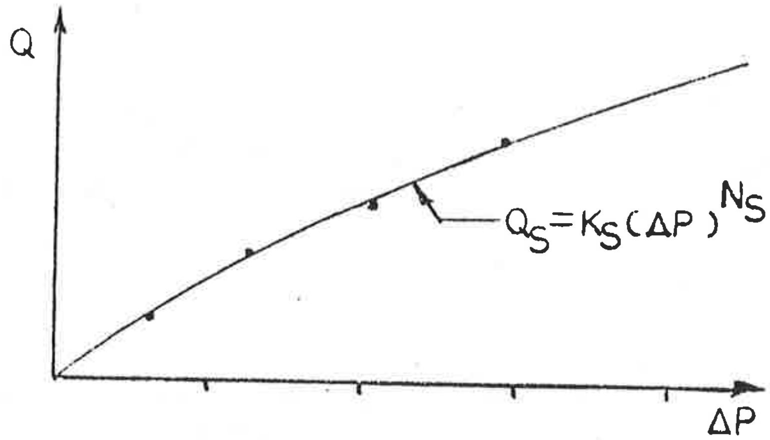


FIGURE NO. 16: Q_S versus ΔP

8. To obtain the air permeance (P), resistance (R), equivalent leakage area (ELA) and the equivalent diameter (Diam.ELA) of a flexible or loose fill specimen, the procedure is identical to the description given in steps 4, 5, 6 and 7 for rigid materials.

6.6 ERROR ANALYSIS

6.6.1 PURPOSE

The main purpose of an error analysis is to evaluate the accuracy of the end results. This accuracy is represented by the percentage of error on the air flow results for each material.

6.6.2 METHOD OF ANALYSIS

In order to achieve this goal, a method has been developped to assess the errors of experimentation and to compute the propagation of these errors through calculation of test results (a detailled description of the method is given in appendix "B").

6.6.3 SOURCES OF ERRORS

The sources of errors are divided into two categories: systematic errors and calculation errors.

Systematic errors

These errors are directly related to the test procedure and apparatus. They include:

- Accuracy and resolution of each instrument;
- Measurement of test conditions (temperature, barometric pressure and differential pressure across specimen);
- Measurement of the specimen effective area.

Calculation errors

These errors are the result of the arithmetic operations needed to determine the air flow through the specimen.

- Propagation of systematic errors through formulas and equations.

6.6.4 DESCRIPTION OF THE METHOD

For each specimen tested, the error analysis method consists of evaluating the maximum possible percentage of error which can be assigned to the air flow rate per unit area. This relative error is given as a function of the pressure differential sustained by the specimen.

The procedure for evaluating the systematic errors are the same for rigid, flexible and loose materials. On the other hand, the propagation of error is different for rigid materials versus flexible and loose materials. This difference is related to the distinct test and calculation procedures.

As a result of the differences, the error analysis method is described hereafter, in three separate steps.

1. Assessment of the systematic errors.
2. Propagation of error for rigid materials.
3. Propagation of error for flexible and loose materials.

Note: To simplify the writing, every percentage of error which should be expressed by ± (E)% will be represented by E.

1. ASSESSMENT OF THE SYSTEMATIC ERRORS

a) Reporting of the standard air flow rate for a given operating condition requires measuring the following parameters where systematic errors are possible:
   - ΔP across the laminar flowmeter;
   - P upstream of the laminar flowmeter;
   - Barometric pressure;
   - T upstream of the laminar flowmeter;
   - Effective area of the specimen;
   - ΔP across the specimen which is assumed to be at STP.

b) The maximum possible percentage of error on the standard flow rate measurement is defined as E_{SFD}.

   where: SFD = Standard flow rate.

c) The maximum possible percentage of error on the measurement of ΔP across the specimen is defined as $E_{\Delta P}$.

d) To evaluate the maximum possible percentage of error E_{IQ} on the value of Q for a given range of ΔP refer to Figure no. 17.

From these two equations and the equation of Q, it is possible to obtain E_Q which is the maximum possible percentage of error on Q. It is important to note that the Q refered to in this section does not have a subscript. This is because it does not represent any particular flow rate equation (ex: leakage, leakage + specimen, etc.).

e) As a result of all those procedures, E_Q is the maximum systematic error on the air flow rate measurement (Q). In order to evaluate E_Q for any ΔP, the equation of E_Q as a function of ΔP is:

$$E_Q = K\,(\Delta P)^n$$

During the determination of the air flow rate through a specimen (Q_S) for rigid, flexible or loose material, the above equation can be used to evaluate the propagation of error through the calculation.

2. PROPAGATION OF ERRORS FOR RIGID MATERIALS

a) As covered in section 6.5.1 the formula used to determine Q_S is:

$$Q_{Si} = Q_{LSi} - Q_{Li} \quad \text{at } \Delta P_i$$

Given: E_{QLS} and E_{QL} for any ΔP

From the theory of error propagation:

$$E_{QSi} = \left[\frac{Q_{LSi} + Q_{Li}}{Q_{LSi} - Q_{Li}}\right]\left[\left[\frac{Q_{LSi}}{Q_{LSi} + Q_{Li}}\right] E_{QLSi} + \left[\frac{Q_{Li}}{Q_{LSi} + Q_{Li}}\right] E_{Li}\right] \text{at} \quad P_i$$

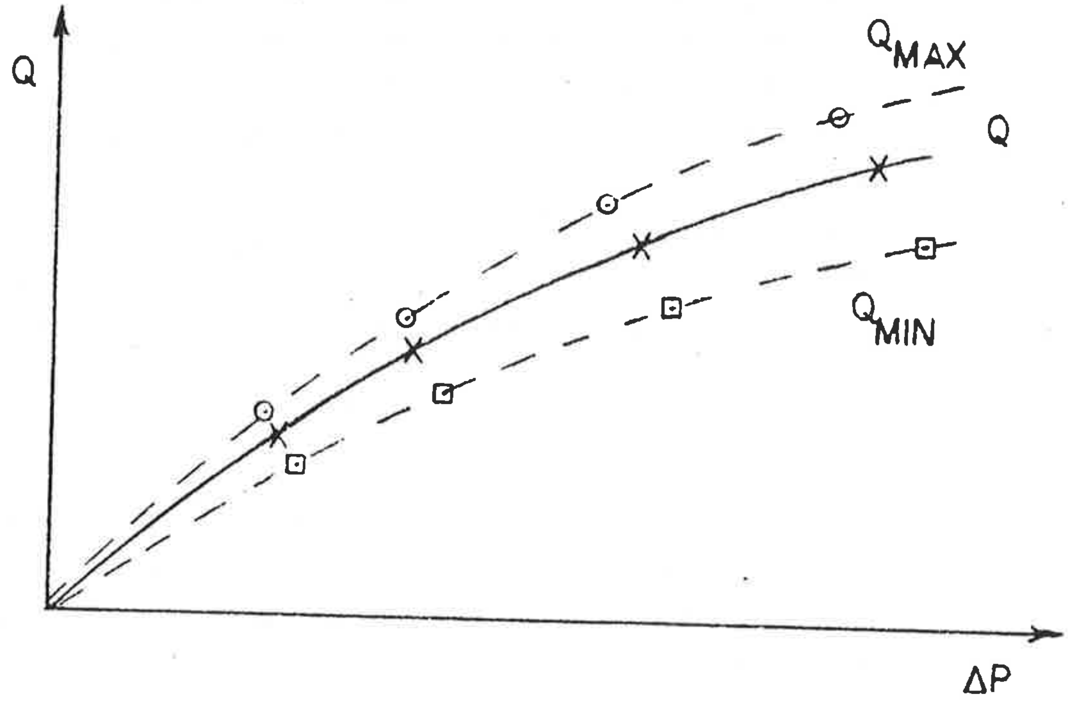


FIGURE NO. 17: Q versus ΔP

Legend:

x : experimental data

⊙ : Plotting of $Q\ (1 + E_{SFD}/100)$ versus $P\ (1 - E_{\Delta P}/100)$

⊡ : Plotting of $Q\ (1 - E_{SFD}/100)$ versus $P\ (1 + E_{\Delta P}/100)$

From the Figure no. 17;

$$Q_{maximum} = Q\ (1 + E_Q/100)$$

$$Q_{minimum} = Q\ (1 - E_Q/100)$$

3. PROPAGATION OF ERRORS FOR FLEXIBLE AND LOOSE MATERIALS

a) As covered in section 6.5.2 the formulas and graph used to determine Q_S are:

$$Q_{SMi} = Q_{LSMi} - Q_{Li} \text{ at } \Delta P_i$$

$$Q_{Mi} = Q_{LMi} - Q_{Li} \text{ at } \Delta P_i$$

and Figure no. 15

Given: E_{QLSMi}, E_{QLMi} and E_{QL} for any ΔP

From the theory of error propagation:

$$E_{QSMi} = \left[\frac{Q_{LSMi} + Q_{Li}}{Q_{LSMi} - Q_{Li}}\right]\left[\left[\frac{Q_{LSMi}}{Q_{LSMi} + Q_{Li}}\right] E_{QLSM} + \left[\frac{Q_{Li}}{Q_{LSMi} + Q_{Li}}\right] E_L\right] \text{at } \Delta P_i$$

$$E_{QMi} = \left[\frac{Q_{LMi} + Q_{Li}}{Q_{LMi} - Q_{Li}}\right]\left[\left[\frac{Q_{LMi}}{Q_{LMi} + Q_{Li}}\right] E_{QLM} + \left[\frac{Q_{Li}}{Q_{LMi} + Q_{Li}}\right] E_L\right] \text{at } \Delta P_i$$

b) The equations of E_{QSM} and E_{QM} as functions of P are obtained from the results of the above formulas and are:

$$E_{QSM} = K_{EQSM} (\Delta P)^{nEQSM}$$

$$E_{QM} = K_{EQM} (\Delta P)^{nEQM}$$

These are the maximum relative error on Q_{SM} and Q_M.

c) To determine the error $E_{\Delta PS}$ on the pressure drop through the specimen (ΔP_S) at various flow rates, use the graph represented in Figure no. 18.

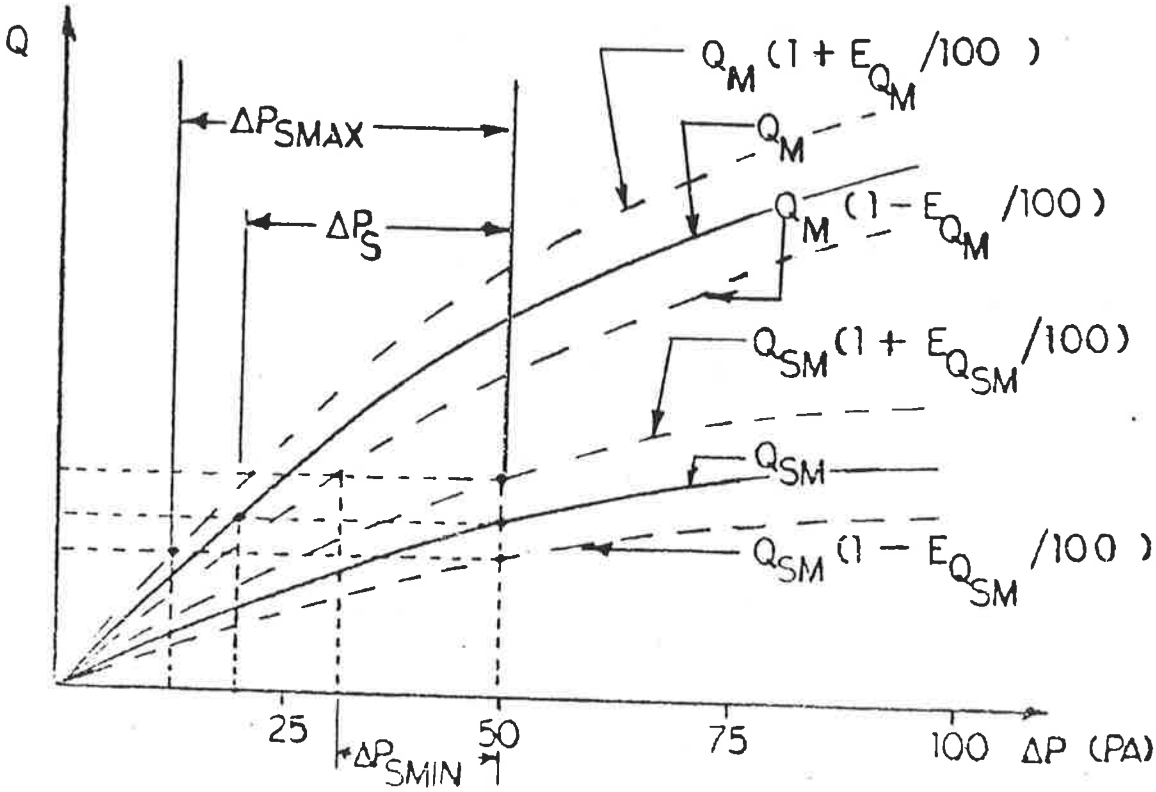


FIGURE NO. 18: Q versus ΔP

From Figure no. 18:

$$P_{SMAX} = P_S \left[1 + \frac{E_{\Delta PS}}{100} \right]$$

$$P_{SMIN} = P_S \left[1 + \frac{E_{\Delta PS}}{100} \right]$$

The two equations above are used to determine the maximum percentage of error on ΔP_S when ΔP_S equals 25, 50, 75 and 100 Pa.

d) To evaluate the maximum possible percentage of error E_{QS} on the value of Q_S for a given range of ΔP refer to Figure no. 19.

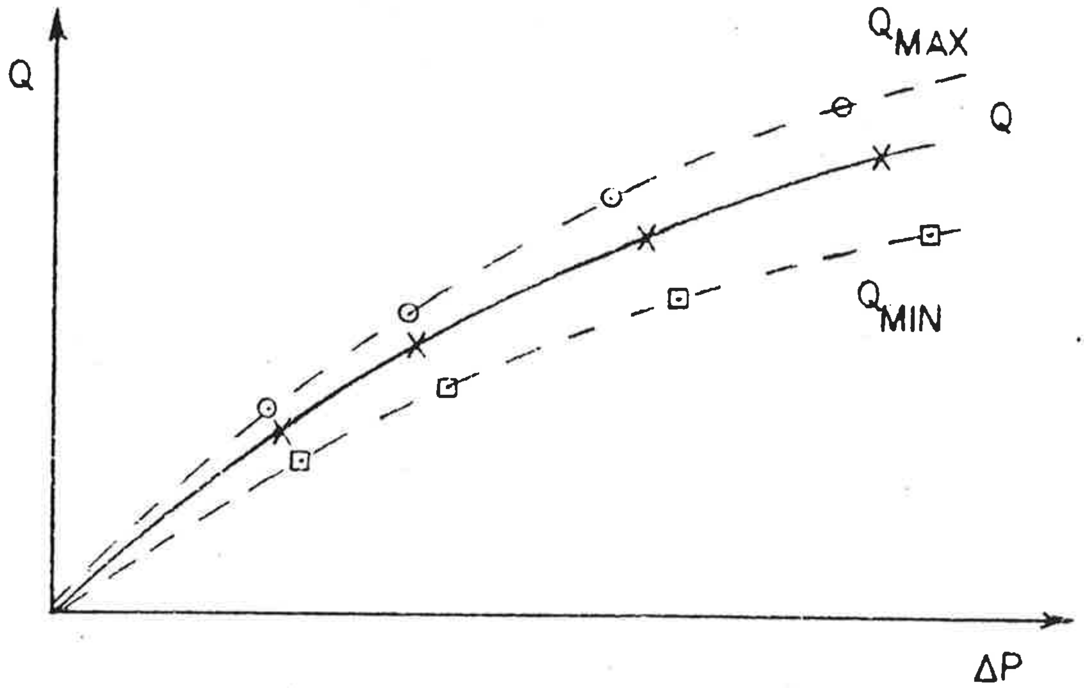


FIGURE NO. 19: Q versus ΔP

Legend:

x : experimental data

⊙ : Plotting of Q_{SM} $(1 + E_{QSM}/100)$ versus P_S $(1 - E_{\Delta PS}/100)$

⊡ : Plotting of Q_{SM} $(1 - E_{QSM}/100)$ versus P_S $(1 - E_{\Delta PS}/100)$

From the Figure no. 19;

$$Q_{SMAX} = Q_S\ (1 + E_{QS}/100)$$

$$Q_{SMIN} = Q_S\ (1 - E_{QS}/100)$$

The two equations above and the value of Q_S are used to determine the maximum percentage of error E_{QS} on Q_S, which can be represented by:

$$E_{QS} = K_{EQS} (\Delta P)^{nEQS}$$

7. VALIDATION OF TEST METHOD

7.1 INTRODUCTION

To verify the precision of the testing equipment at AIR-INS Inc., measurements of air flow rate versus ΔP have been carried-out on the same components at the "Institute for Research in Construction" (IRC).

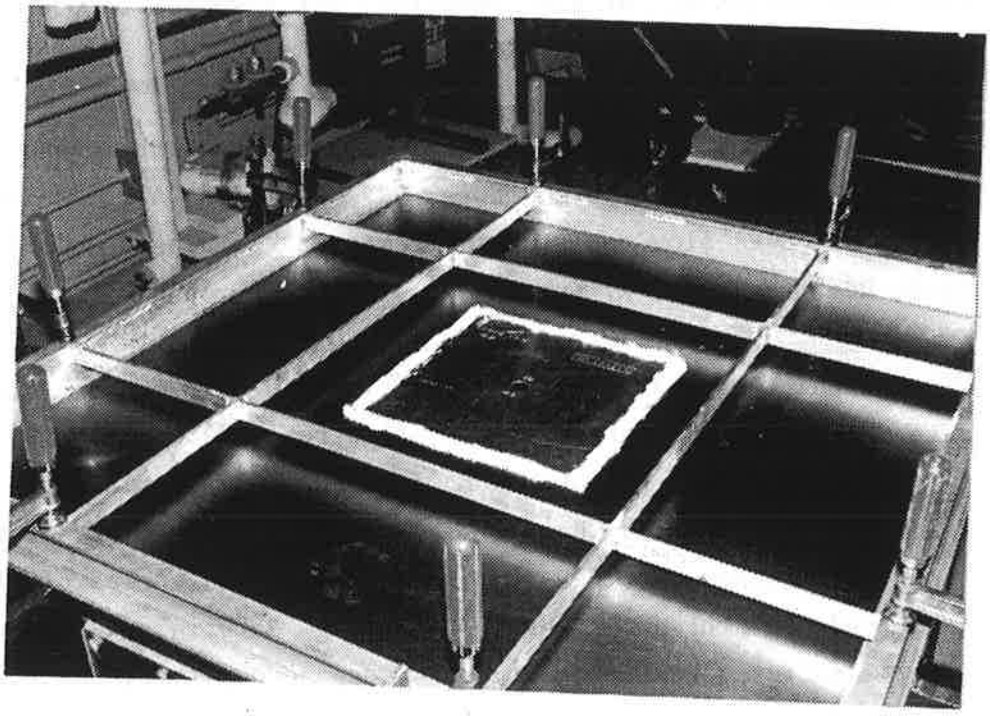
The test method used by IRC is similar to the test method reported in the Building Research Note 227 titled: "A test method to determine air flow resistance of exterior membranes and sheatings" by M. Bomberg and M. K. Kumaran.

Validation included two steps. Prior to the testing of building materials, measurements of air flow rate (Q) at various pressure differences (ΔP) were taken on four (4) orifice plates using both testing facilities. Then, to insure the reliability of the test results obtained at AIR-INS Inc., a second series of tests was conducted on three different building materials. The selected materials were: tempered hardboard, expanded polystyrene type 1 and type 2.

7.2 SELECTION OF ORIFICE SIZES AND BUILDING MATERIALS

7.2.1 ORIFICE SIZES

Orifice sizes were selected on the basis that they would exceed the range of air flow rates suggested by IRC for air-barrier systems (Q = 0.05 L/s-m^2 to 0.15 L/s-m^2 at P = 75 Pa). In order to reach better precision, the minimum measurable flow has been selected to be approximately 0.0005 l/s-m^2 and the maximum measurable flow to be approximately 15 $l/s\text{-}m^2$. The main reason for attempting to reach such a maximum measurable air flow was to determine the permeance of loose fill materials. To cover the complete range of measurable flow, four orifice sizes were selected (3/64 in., 13/64 in., 7/8 in. and 4 x 1 in.). Photograph no. 6 shows a typical orifice plate.



Photograph no. 6: Orifice plate

7.2.2. BUILDING MATERIALS

Specimens were selected in such a way that they had to be rigid and their permeance had to differ greatly. This in order to represent the least, intermediate and the most permeable material. The selection consisted of three boards. Two were 25mm thick expanded polystyrene (type 1 and type 2). The third was a tempered hardboard (3mm (1/8 in.)).

7.3 PREPARATION OF TEST SPECIMEN AND TEST SEQUENCE

7.3.1 ORIFICES

For IRC, a complete description of the preparation and test sequence for a given orifice is given in Appendix "C".

Figure no. 20 shows the main components of both tests apparatus with an orifice.

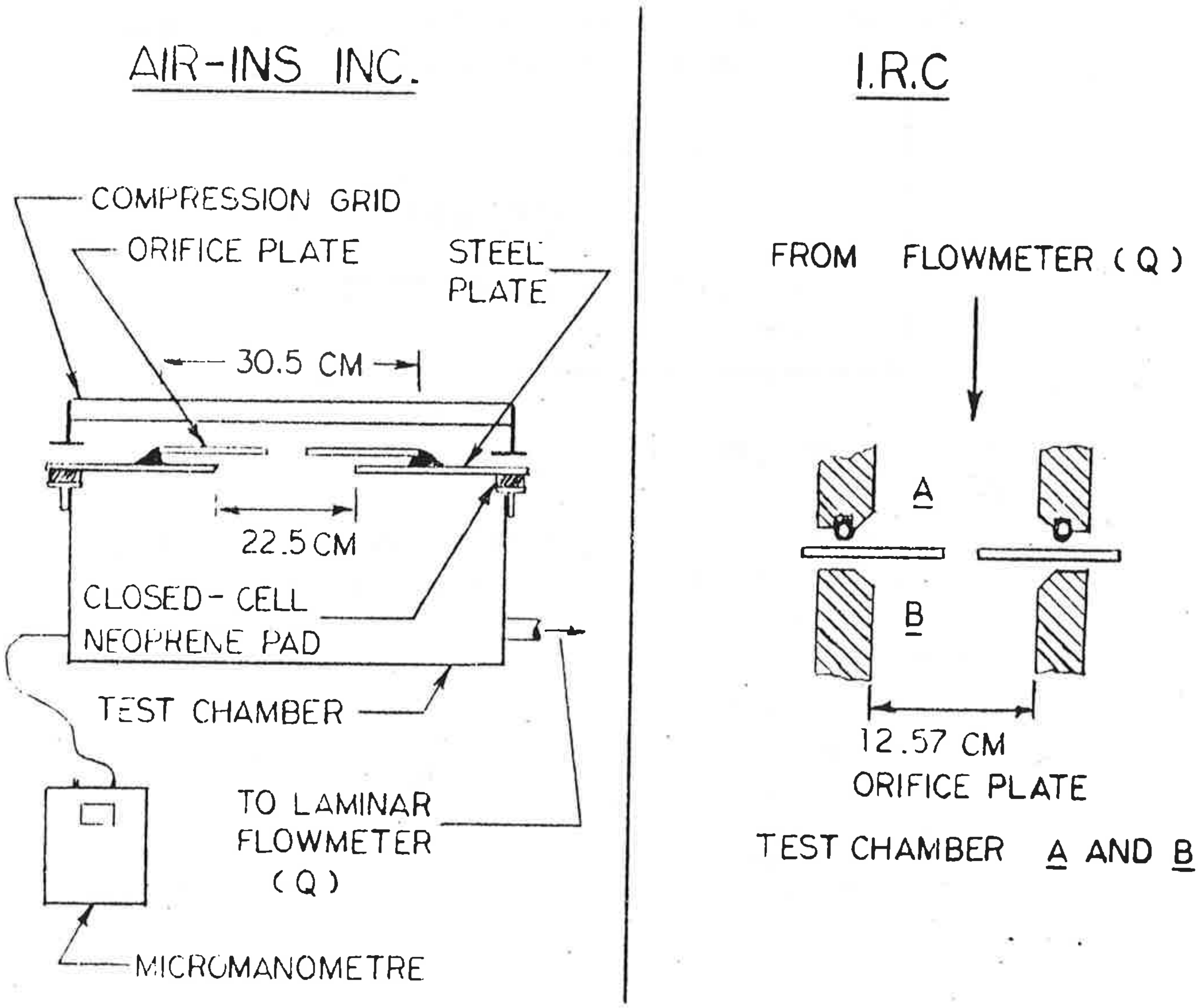


FIGURE NO. 20: TEST APPARATUS

At AIR-INS Inc. the test sequence can be summarized by the following steps:

1. a) With a polyethylene film (6 mil) taped over the orifice plate, measure the air leakage rate (Q_L) from the test chamber at various pressure differentials (ΔP);

   b) Correct the air leakage rate (Q_L) to STP ($T = 20^oC$ and $P = 101.325$ kPa)

   c) Using an equation of the form $Q_L = K_L (\Delta P)^{nL}$ to represent the dependence of Q on P, determine the constants "K_L" and "nL" which represent the best fit. Figure no. 21 gives a graphical representation of the above operations.

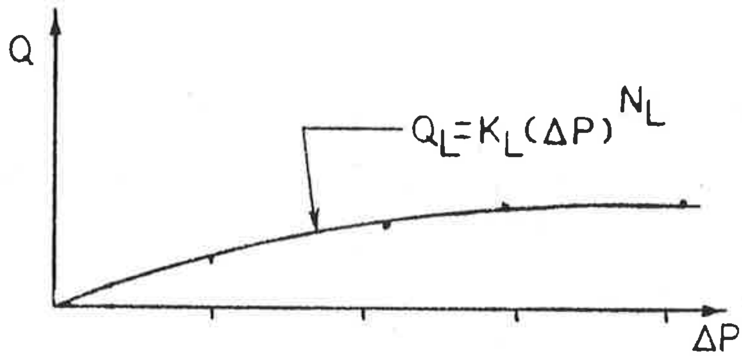


FIGURE NO. 21: Q_L versus P

2. a) Upon removal of the polyethylene film over the orifice, measure the total air flow rate from the test chamber and from the orifice (Q_{LO}) at various pressure differentials (ΔP);

   b) Correct Q_{LO} to STP;

   c) Using an equation of the form $Q_{LO} = K_{LO} (\Delta P)^{nLO}$ to represent the dependence of Q_{LO} on ΔP, determine the constants "K_{LO}" and "nLO" which represent the best fit. Figure no. 22 gives a graphical representation of the above operations.

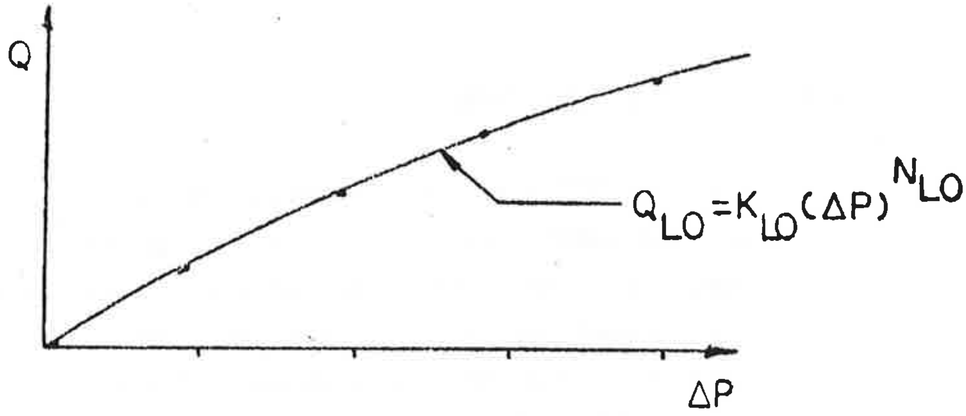


FIGURE NO. 22: Q_{LO} versus P

3. a) To determine the flow rate through the orifice (Q_0) at various pressure differentials (ΔP), substract "Q_L" from Q_{LO}" at the following static pressure differentials (25, 50, 75, 100 Pa).

b) Using an equation of the form $Q_0 = K_0 (\Delta P)^{n0}$ to represent the dependence of Q_0 on ΔP, determine the constants "K_0" and "n0" which represent the best fit. Figure no. 23 gives a graphical representation of the above operations.

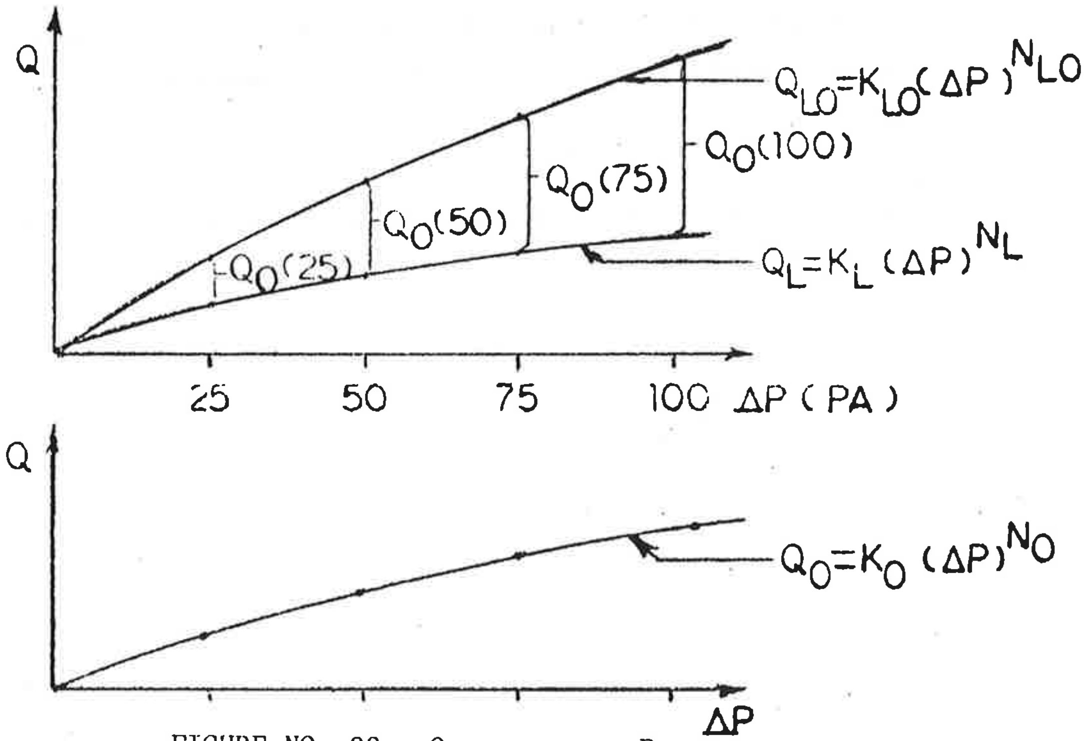


FIGURE NO. 23: Q_0 versus P

7.3.2 BUILDING MATERIALS

Appendix "C" gives an extensive description of the preparation and test sequence for all specimens tested at IRC. Because of size limitations for the test apparatus, each board was divided into nine equal squares. A circular specimen was cut, 125mm in diameter, from the center of each of these nine squares and sealed into a Plexiglas ring of the same diameter with RTV silicone rubber. Thus, nine test specimens (0.012 m^2 area) were prepared from each board.

Article 6 gives a complete description of the preparation and test sequence for all specimens tested at AIR-INS Inc.

7.4 TEST RESULTS

7.4.1 ORIFICES

The results from measurements made at IRC on plates no. 1 and 2 are given in Tables 1 and 2. Also given in the tables are air flow rates calculated according to the flow-equation found by AIR-INS Inc.

Table 3 gives the flow-equation ($Q_0 = K_0 (\Delta P)^{n0}$) found by AIR-INS Inc. for each plate.

Table 1: Experimental data on "Orifice Plate No.1, 3/64 inch hole", Q is the volumetric air flow rate and (ΔP) is the pressure difference at the steady state.

	IRC	AIR-INS Inc.
P (Pa)	Q (L/S)	Q(Calculated) (L/S)
3.9	0.00259	0.00242
5.9	0.00323	0.00306
11.0	0.00453	0.00436
16.6	0.00582	0.00550
30.8	0.00808	0.00779
49.0	0.01035	0.01013
60.7	0.01164	0.01143
73.9	0.01293	0.01278
92.0	0.01455	0.01446

Table 2: Experimental data on "Orifice Plate No.2, 13/64 inch hole", Q is the volumetric air flow rate and (ΔP) is the pressure difference at the steady state.

	IRC	AIR-INS Inc.
P (Pa)	Q (L/S)	Q(Calculated) (L/S)
6.9	0.0573	0.0459
9.8	0.0650	0.0551
13.7	0.0745	0.0657
15.7	0.0762	0.0706
15.7	0.0765	0.0706
20.6	0.0867	0.0814
31.3	0.1073	0.1014
34.3	0.1122	0.1064
48.0	0.1311	0.1269
63.6	0.1500	0.1471
82.2	0.1688	0.1683
104.8	0.1877	0.1912

Table 3: AIR-INS Inc. FLOW EQUATIONS * (ORIFICES)

PLATE NO.	ORIFICE NOMINAL SIZE		FLOW EQUATION $Q_o = K_o (P)^{no}$
	mm	(in.)	Q_o : L/S P: Pa
1	1.19	3/64	$Q_o = 0.001083 (P)^{0.572987}$
2	5.16	13/64	$Q_o = 0.015951 (P)^{0.534991}$
3	22.2	7/8	$Q_o = 0.315643 (P)^{0.518784}$
4	4x25.4	4x1	$Q_o = 1.655549 (P)^{0.500636}$

* Detailed test results for all orifice plates may be found in Appendix "C" (IRC) and Appendix "E" (AIR-INS Inc.)

- The above equations are reported at STP.

Figures 24 and 25 compare for plates no.1 and 2 the experimental data found by IRC versus those calculated by AIR-INS Inc.

Plates no. 3 and 4 were not tested by IRC since the size of the hole(s) was much larger than can be accommodated by the experimental set-up.

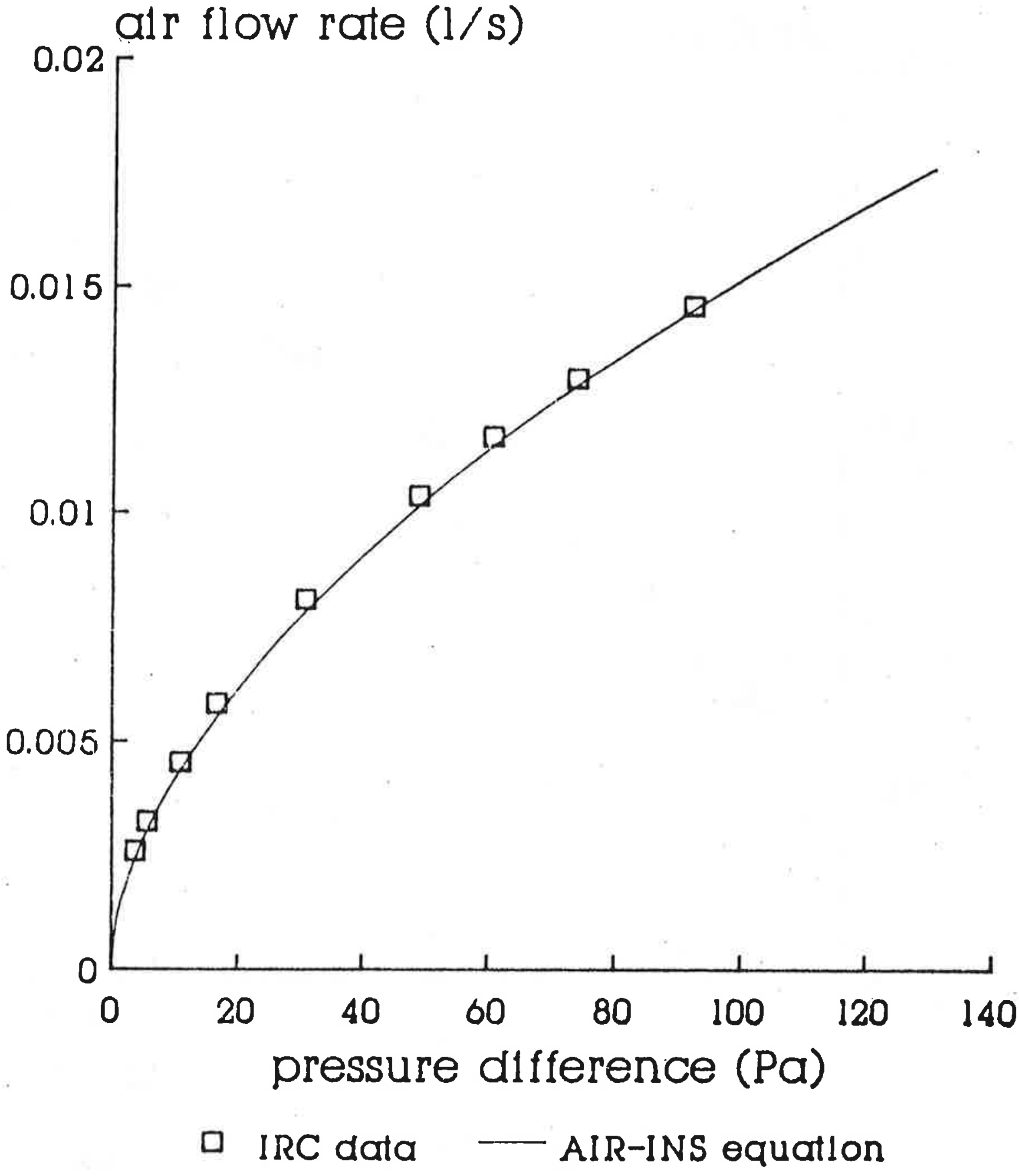


FIGURE NO.24: PLATE NO. 1

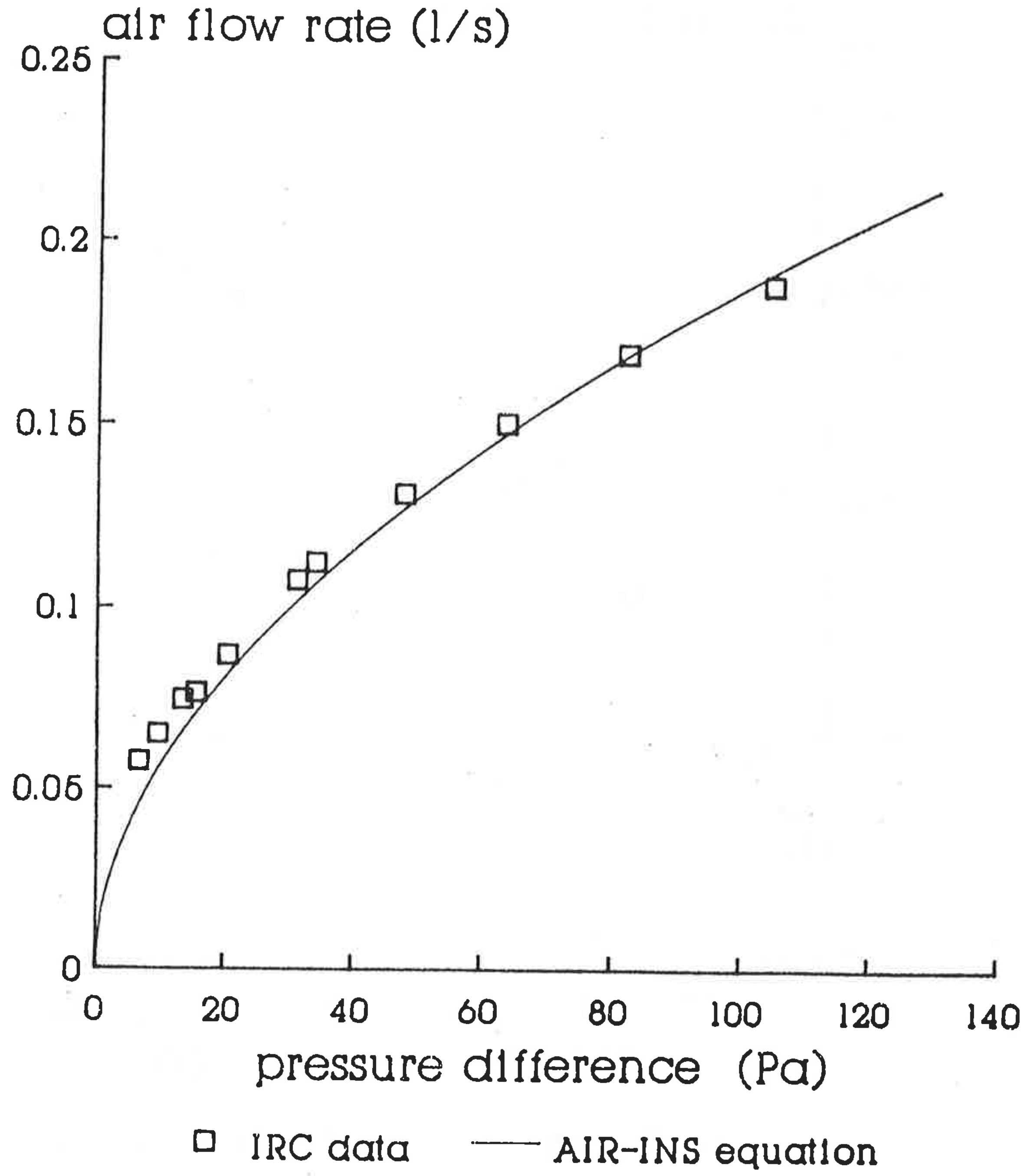


FIGURE NO. 25: PLATE NO. 2

7.4.2 BUILDING MATERIALS

The results from measurements made at IRC on the three building materials are given in Appendix "C" and are plotted in Figures no. 26 to 28. Also plotted in the figures are the averages of experimental data acquired by IRC and the values given by AIR-INS Inc. equation for each board. The average values were determined for each board through least-squares analysis of all nine sets of data, each data pair having been weighted equally.

Detailed AIR-INS Inc. test results on the same building materials may be found in Appendix "E". To summarize results, Table 4 gives the flow-equation ($Q = K\ (\Delta P)^{n}$) found for each building material.

Table 4: AIR-INS Inc. FLOW EQUATIONS (BUILDING MATERIALS)

MATERIAL	SPECIMEN NO.	FLOW EQUATION $Q = K\ (\ \ P)^{n}$
Tempered hardboard	19 A	$Q = 0.002731\ (\ \ P)^{1}$
Expanded polystyrene type 1	33 E	$Q = 0.276677\ (\ \ P)^{0.911}$
Expanded polystyrene type 2	34 A	$Q = 0.001882\ (\ \ P)^{0.9955}$

- Q : L/S and P: Pa
- The above equations are reported at STP.

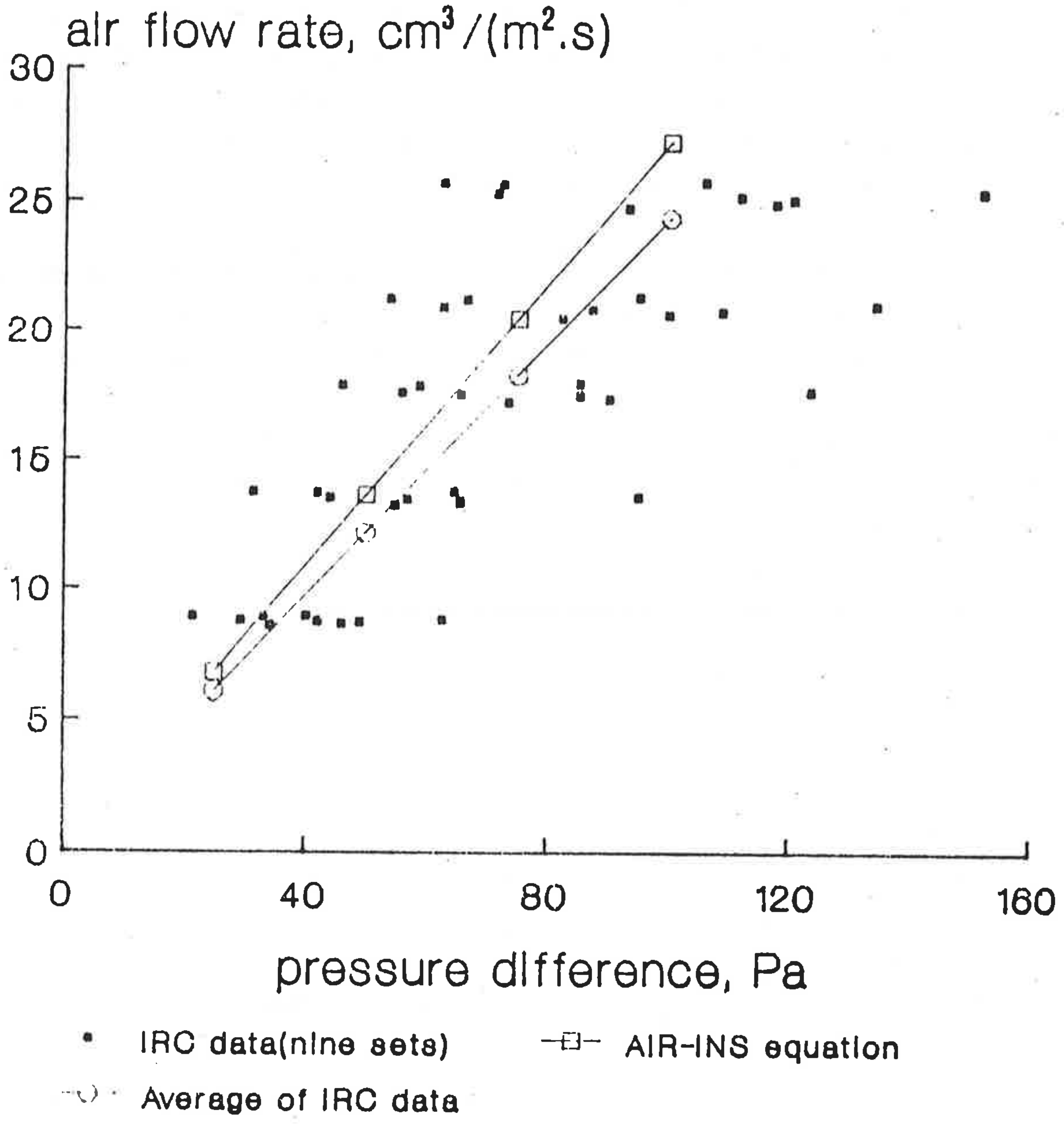


FIGURE NO. 26: SPECIMEN NUMBER 19 A
(TEMPERED HARDBOARD)

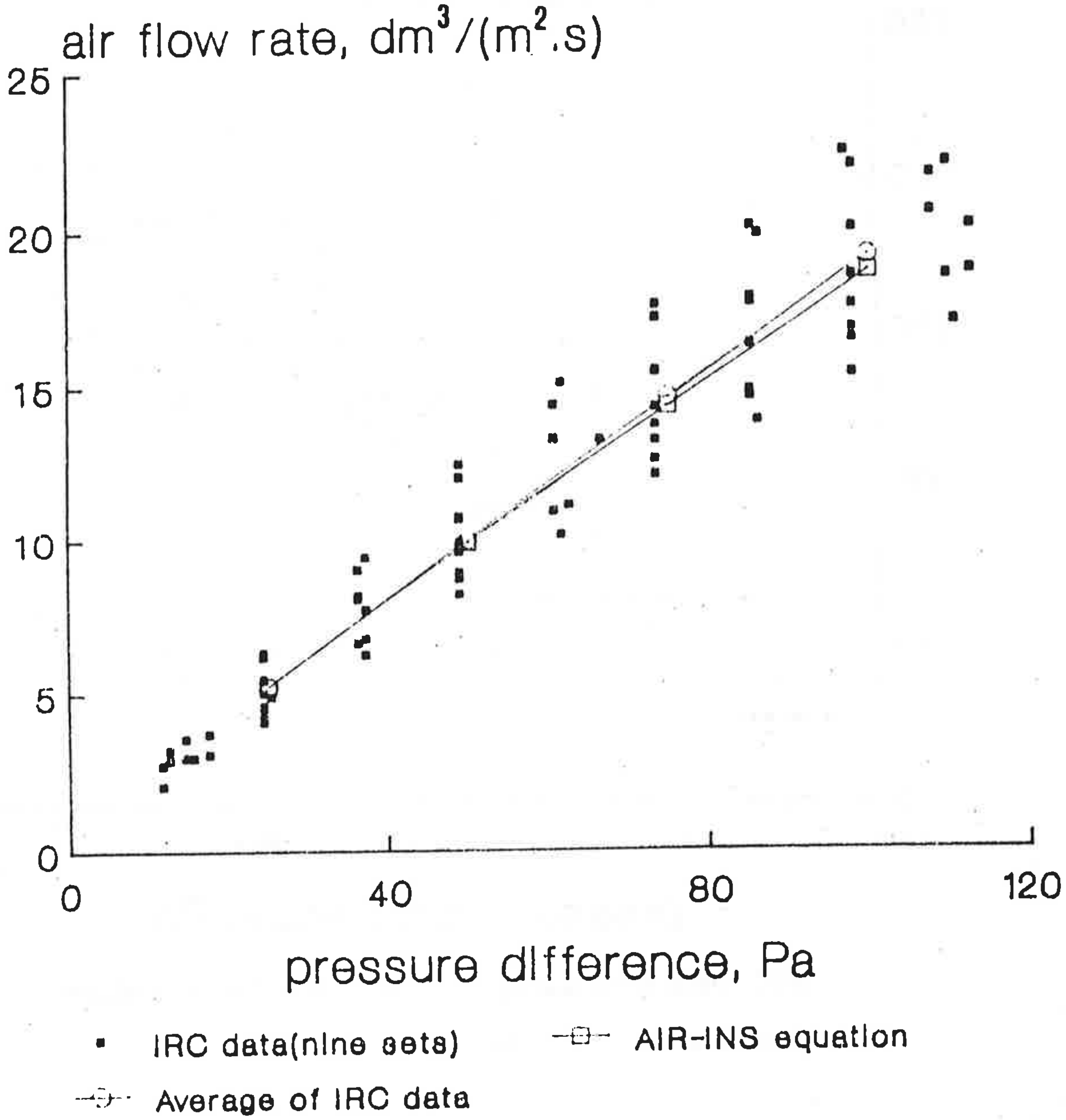


FIGURE NO.27 : SPECIMEN NUMBER 33 E
(EXPANDED POLYSTYRENE TYPE 1)

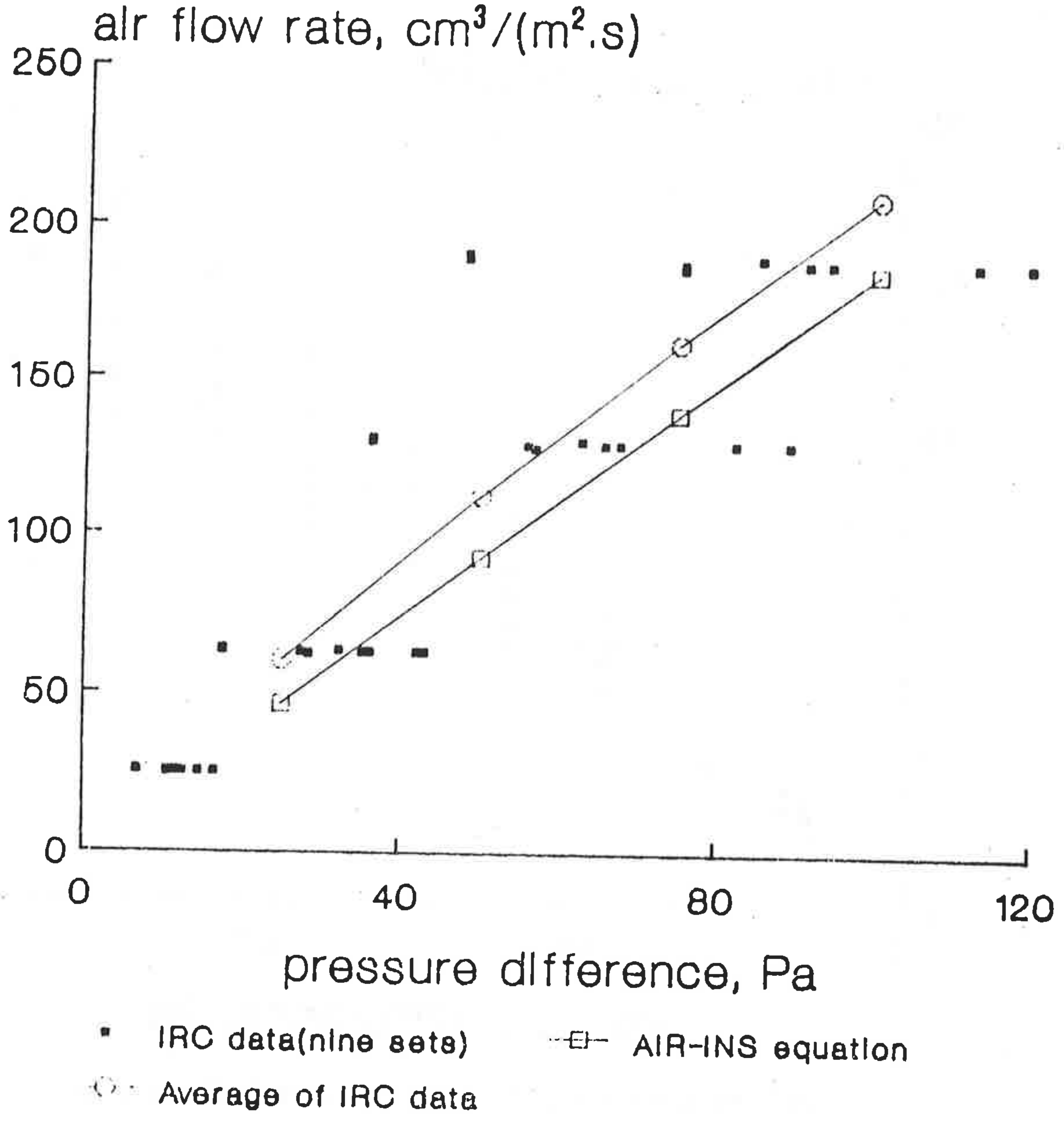


FIGURE NO.28 : SPECIMEN NUMBER 34 A
(EXPANDED POLYSTYRENE TYPE 2)

8. APPLICATION OF THE TEST METHOD

The test method described in article 6 was used to determine air permeance (P), resistance (R), equivalent leakage area (ELA) and the equivalent diameter (Diam.ELA) of thirty-six (36) different building materials; these included twenty-one (21) rigid materials board, thirteen (13) flexible materials and two (2) loose materials. Table 5 gives a list of materials tested and Appendix "D" shows a description of these materials.

Each material was tested as per the following procedure:

1) For materials showing a very small air permeance (8 x 10^{-8} m/Pa-S) at ΔP = 75 Pa, two specimens to be tested and reported as non-measurable.

2) For materials showing a measurable air permeance (8 x10^{-8} m/Pa-S) at 75 Pa, five specimens to be tested and the results reported as:

   a) Average air flow rate (Q_{AVG}) through the material at ΔP= 75 Pa;

   b) Minimum measured air flow rate (Q_{MIN}) through the specimen at ΔP= 75 Pa;

   c) Maximum measured air flow rate (Q_{MAX}) through the specimen at ΔP= 75 Pa;

   d) Average air permeance (P_{AVG}) of the material at ΔP=75 Pa;

   e) Average resistance (R_{AVG}) of the material at ΔP= 75 Pa;

   f) Average constant values ("K_{AVG}" and "n_{AVG}") in the equation $Q = K_{AVG} (\Delta P)^{nAVG}$;

   g) Classification of the material with respect to the rating suggested by IRC for air-barrier systems. Table 6 shows the classification of air-barrier systems.

TABLE 5: LIST OF MATERIALS TESTED

MATERIAL NO.	DESCRIPTION	THICKNESS	TYPE*
1	Spunbonded olefin film	3 mil	F
2	Perforated polyethylene film no. 1	3 mil	F
3	Perforated polyethylene film no. 2	3 mil	F
4	Roofing bituminous membrane	2 mm	F
5	Modified bituminous membrane	2.7 mm	F
6	Reinforced non-perforated polyolefin film	4 mil	F
7	Cellulose fibre spray-on insulation	38 mm	R
8	Reflective vapor barrier		F
9	Non-perforated asphalt felt (15 lb)		F
10	Asphalt felt with air vents (15 lb)		F
11	Saturated roofing felt (30 lb)		F
12	Self-adhesive membrane	1.3 mm	F
13	Modified bituminous membrane	2.7 mm	F
14	Gypsum board	12.7 mm	R
15	High humidity resistance gypsum board	12.7 mm	R
16	Tempered hardboard	3.2 mm	R
17	Glass wool insulation	152 mm	L
18	3 ply plywood sheathing	8 mm	R
19	3 ply plywood sheathing	9.5 mm	R
20	Flake wood board	11 mm	R
21	Flake wood board	16 mm	R
22	Particle board	12.7 mm	R
23	Particle board	16 mm	R
24	Plain fibreboard	11 mm	R

TABLE 5: LIST OF MATERIALS TESTED (Continued)

MATERIAL NO.	DESCRIPTION	THICKNESS	TYPE*
25	Fiberboard (asphalt coated on both faces)	11 mm	R
26	Tongue and groove planks (15 mm x 127 mm)	15 mm	R
27	Extruded polystyrene	38 mm	R
28	Urethane board faced with aluminum foil on both faces	25.4 mm	R
29	Expanded polystyrene - type 1	25.4 mm	R
30	Expanded polystyrene - type 2	25.4 mm	R
31	Phenolic insulation board with kraft paper on both faces	24 mm	R
32	Phenolic insulation board with kraft paper on both faces	42 mm	R
33	Glass fibre, with a spunbonded olefin film on one side		F
34	Vermiculite loose fill insulation	75 mm	L
35	Cement board	12.7 mm	R
36	Aluminum foil back gypsum board	12.7 mm	R

* F: Flexible, R: Rigid, L: Loose

TABLE 6: CLASSIFICATION OF AIR-BARRIER SYSTEMS (IRC)

RATING	INSIDE RH at 21°C	MAXIMUM AIR FLOW at 75 Pa
	(%)	($L/S\text{-}m^2$)
TYPE 1	27	0.15
TYPE 2	27 RH 55	0.10
TYPE 3	55	0.05

3) At least four data pairs (Q and P) to be used to calculate all the equations $Q = K\,(\Delta P)^n$;

4) Each data pair to be measured at P near 25, 50, 75 and 100 Pa;

9. BUILDING MATERIALS TEST RESULTS

Detailed test results for all materials may be found from Appendix "E".

Results are summarized in Tables 7 and 8. Table 7 lists all materials showing non-measurable air flows, while Table 8 lists in ascending order the materials which showed a measurable air flow at pressure differentials varying from 25 to 100 Pa.

Table 9 gives the average equivalent leakage area (ELA_{AVG}) and equivalent orifice diameter (Diam.ELA) for all materials which showed measurable air flow rates.

TABLE 7: MATERIALS SHOWING A NON-MEASURABLE AIR FLOW
($P_{AVG} < 8 \times 10^{-8}$ m/Pa-S)

MATERIAL (no.)	DESCRIPTION
4	2 mm, smooth surface roofing membrane
5	2.7 mm, modified bituminous torch on grade membrane (glass fiber mat)
8	Aluminum foil vapor barrier
12	1.3 mm, modified bituminous self-adhesive membrane
13	2.7 mm, modified bituminous torch on grade membrane (polyester reinforced mat)
19	9.5 mm, plywood sheathing
27	38 mm, extruded polystyrene
28	25.4 mm, foil back urethane insulation
31	24 mm, phenolic insulation board
32	42 mm, phenolic insulation board
35	12.7 mm, cement board
36	12.7 mm, foil back gypsum board

TABLE 8: MATERIALS HAVING A MEASURABLE AIR FLOW

MATERIAL NO.	DESCRIPTION	Q_{AVG} at 75 Pa $(L/S\text{-}m^2)$	Q_{MIN} at 75 Pa $(L/S\text{-}m^2)$	Q_{MAX} at 75 Pa $(L/S\text{-}m^2)$	R_{AVG} at 75 Pa (Pa-s/m)	P_{AVG} at 75 Pa (m/pa-s)	K_{AVG}	N_{AVG}	RATING AS PER IRC
18	8 mm plywood sheathing	0,0067	0,0000	0,0222	$1.13\text{x}10^{7}$	$8.87\text{x}10^{-8}$	0,00011	0,944	3
21	16 mm flakewood board	0,0069	0,0006	0,0181	$1.09\text{x}10^{7}$	$9.19\text{x}10^{-8}$	0,00010	0,979	3
15	12.7 mm Gypsum board (M/R)	0,0091	0,0055	0,0118	$8.23\text{x}10^{6}$	$1.22\text{x}10^{-7}$	0,00012	1,000	3
20	11 mm flakewood board	0,0108	0,0075	0,0134	$6.92\text{x}10^{6}$	$1.45\text{x}10^{-7}$	0,000145	0,998	3
22	12.7 mm particle board	0,0155	0,0121	0,0178	$4.84\text{x}10^{6}$	$2.07\text{x}10^{-7}$	0,000210	0,996	3

TABLE 8: MATERIALS HAVING A MEASURABLE AIR FLOW (continued)

MATERIAL NO.	DESCRIPTION	Q_{AVG} at 75 Pa	Q_{MIN} at 75 Pa	Q_{MAX} at 75 Pa	R_{AVG} at 75 Pa	P_{AVG} at 75 Pa	K_{AVG}	N_{AVG}	RATING AS PER IRC
		$(L/S\text{-}m^2)$	$(L/S\text{-}m^2)$	$(L/S\text{-}m^2)$	(Pa-s/m)	(m/pa-s)			
6	Reinforced non-perforated polyolefin	0,0195	0,0171	0,0218	$3.84x10^{6}$	$2.60x10^{-7}$	0,000272	0,989	3
14	12.7 Gypsum board	0,0196	0,0170	0,0219	$3.83x10^{6}$	$2.61x10^{-6}$	0,000266	0,995	3
23	15.9 mm particle board	0,0260	0,0130	0,0375	$2.88x10^{6}$	$3.47x10^{-7}$	0,000431	0,949	3
16	3.2 mm tempered hardboard	0,0274	0,0184	0,0422	$2.73x10^{6}$	$3.66x10^{-7}$	0,000399	0,979	3

TABLE 8: MATERIALS HAVING A MEASURABLE AIR FLOW (continued)

MATERIAL NO.	DESCRIPTION	Q_{AVG} at 75 Pa	Q_{MIN} at 75 Pa	Q_{MAX} at 75 Pa	R_{AVG} at 75 Pa	P_{AVG} at 75 Pa	K_{AVG}	N_{AVG}	RATING AS PER IRC
		$(L/S\text{-}m^2)$	$(L/S\text{-}m^2)$	$(L/S\text{-}m^2)$	(Pa-s/m)	(m/pa-s)			
30	expanded polystyrene type 2	0,1187	0,0214	0,2799	$6.32x10^5$	$1.58x10^{-6}$	0,00163	0,993	1
11	30 lb roofing felt	0,1873	0,1674	0,2081	$4.01x10^5$	$2.50x10^{-6}$	0,002535	0,996	n/c
9	15lb non-perforated asphalt felt	0,2706	0,2480	0,2957	$2,77x10^5$	$3.61x10^{-6}$	0,003607	1,000	n/c
10	15 lb perforated asphalt felt	0,3962	0,3266	0,4774	$1.85x10^5$	$5.28x10^{-6}$	0,006629	0,947	n/c
33	Glass fiber rigid insulation board with a spunbonded olefin film on one face	0,4880	0,4305	0,5781	$1.54x10^5$	$6.51x10^{-6}$	0,006877	0,987	n/c

TABLE 8: MATERIALS HAVING A MEASURABLE AIR FLOW (continued)

MATERIAL NO.	DESCRIPTION	Q_{AVG} at 75 Pa	Q_{MIN} at 75 Pa	Q_{MAX} at 75 Pa	R_{AVG} at 75 Pa	P_{AVG} at 75 Pa	K_{AVG}	N_{AVG}	RATING AS PER IRC
		$(L/S\text{-}m^2)$	$(L/S\text{-}m^2)$	$(L/S\text{-}m^2)$	(Pa-s/m)	(m/pa-s)			
24	11 mm plain fiberboard	0,8223	0,7374	0,8916	9.12×10^{5}	1.10×10^{-5}	0,011470	0,990	n/c
25	11 mm asphalt impregnated fiber board	0,8285	0,7461	0,8942	9.05×10^{4}	1.10×10^{-5}	0,011266	0,995	n/c
1	Spunbonded olefin film	0,9593	0,8410	1,0684	7.82×10^{4}	1.28×10^{-5}	0,012790	1,000	n/c
2	Perforated polyethylene #1	4,0320	2,5558	5,9343	1.86×10^{4}	5.38×10^{-5}	0,201203	0,694	n/c
3	Perforated polyethylene #2	3,2307	2,7986	3,7219	2.32×10^{4}	4.31×10^{-5}	0,187891	0,659	n/c

TABLE 8: MATERIALS HAVING A MEASURABLE AIR FLOW (continued)

MATERIAL NO.	DESCRIPTION	Q_{AVG} at 75 Pa $(L/S\text{-}m^2)$	Q_{MIN} at 75 Pa $(L/S\text{-}m^2)$	Q_{MAX} at 75 Pa $(L/S\text{-}m^2)$	R_{AVG} at 75 Pa (Pa-s/m)	P_{AVG} at 75 Pa (m/pa-s)	K_{AVG}	N_{AVG}	RATING AS PER IRC
29	Expanded polystyrene (type 1)	12,2372	9,4547	15,2111	6.13×10^{3}	1.63×10^{-4}	0,251356	0,900	n/c
26	Tongue and groove planks	19,1165	18,0594	20,1736	3.92×10^{3}	2.55×10^{-4}	1,670934	0,564	n/c
17	Glasswool insulation	36,7327	22,9763	87,9639	2.04×10^{3}	4.90×10^{-4}	0,61088	0,949	n/c
34	Vermiculite insulation	70,4926	32,4266	108,5586	1.06×10^{3}	9.40×10^{-4}	1,0296	0,979	n/c
7	Cellulose insulation (spray on)	86,9457	75,2354	100,3396	8.63×10^{2}	1.16×10^{-3}	1,3217	0,970	n/c

TABLE 9: EQUIVALENT LEAKAGE AREA (ELA) AND (DIAM. ELA)

MATERIAL NO.	DESCRIPTION	ELA (m^2)	DIAM.ELA (mm)
18	8 mm plywood	$3{,}987 \times 10^{-7}$	0,173
21	16 mm flakewood board	$3{,}851 \times 10^{-7}$	0,700
15	12.7 mm Gypsum board M/R	$4{,}879 \times 10^{-7}$	0,788
20	11 mm flakewood board	$5{,}822 \times 10^{-7}$	0,861
22	12.7 mm particle board	$8{,}372 \times 10^{-7}$	1,032
6	Reinforced non preforated polyolefin	$1{,}068 \times 10^{-6}$	1,166
14	12.7 mm gypsum board	$1{,}059 \times 10^{-6}$	1,161
23	15,9 mm particle board	$1{,}543 \times 10^{-6}$	1,401
16	3,2 mm tempered hardboard	$1{,}531 \times 10^{-6}$	1,396
30	Expanded polystyrene type 2	$6{,}443 \times 10^{-6}$	2,864
11	30 lb roofing felt	$1{,}010 \times 10^{-5}$	3,585
9	15 lb non-perforated roofing felt	$1{,}448 \times 10^{-5}$	4,294
10	15 lb perforated roofing felt	$2{,}358 \times 10^{-5}$	5,479

TABLE 9: EQUIVALENT LEAKAGE AREA (ELA) AND (DIAM. ELA) continued

MATERIAL NO.	DESCRIPTION	ELA (m^2)	DIAM.ELA (mm)
33	Glass fiber rigid insulation board, with a spunbonded olefin film on one face	$2,681 \times 10^{-5}$	5,842
24	11 mm plain fiberboard	$4,495 \times 10^{-5}$	7,565
25	11 mm asphalt coated fiberboard	$4,475 \times 10^{-5}$	7,549
1	Spunbonded olefin film	$5,135 \times 10^{-5}$	8,086
3	Perforated polyethylene # 2	$3,439 \times 10^{-4}$	20,924
2	Perforated polyethylene	$3,996 \times 10^{-4}$	22,555
29	Expanded polystyrene type 1	$8,014 \times 10^{-4}$	31,943
26	Tongue and groove plank	$2,461 \times 10^{-3}$	55,975
17	Glass wool insulation	$2,180 \times 10^{-3}$	52,682
34	Vermiculite insulation	$3,937 \times 10^{-3}$	70,803
7	Cellulose insulation (spray on)	$4,948 \times 10^{-3}$	79,370

10. DISCUSSION AND CONCLUSIONS

10.1 TEST METHOD

10.1.1 CONDITIONING

Eventhough all specimens underwent conditioning prior to testing, the team does not believe that this variable will influence the test results if tests are conducted at normal temperature and relative humidity. This is confirmed by the results obtained on three different materials from the two different test apparatus (IRC and AIR-INS Inc.) Furthermore, the time required to perform all tests on a specimen can be as long as two (2) days, this suggests that the specimen is continuously at transient conditions (T and RH). One can therefore suggest that the determination of air permeance of building materials should be conducted at a dry-buld temperature of 20 ± 5°C and a relative humidity of 30 ± 15%.

10.1.2 PREPARATION OF TEST SPECIMENS

Preparation of test specimens is certainly an important variable to consider in order to obtain accurate and repeatable results. At every step of the preparation and while conducting tests, special care must be taken to exclude or eliminate all possible mistakes and errors in the determination of air flow rate through the system.

10.1.3 ERROR ANALYSIS

The systematic error range is between ±5% and ±9% for air flow measurements, which is acceptable. One can therefore conclude that the test procedure and apparatus are appropriate. The percentage of error is inversely proportional to the differential pressure sustained by the specimen. One can therefore suggests that the tests could be conducted under higher differential pressures. The propagation of error in some cases could increase the percentage of error up to ± 150%. Cases such as air tight materials and highly permeable flexible or loose materials are the worst for error propagation due to calculations. However it is important to note that in no case does the influence of error cause the classification of the tested material to change.

10.2 VALIDATION OF TEST METHOD

10.2.1 ORIFICES

For plate no. 1, Table 1 and Figure no. 24 show that for the pressure differential range of 25 to 100 Pa, results from both test methods are within 1% (high ΔP) to 3% (low ΔP) of each other. The deviation is well within the accuracy of both test methods.

For plate no. 2, Table 2 and Figure no. 25 show that for the pressure differential range of 25 to 100 Pa, results from both test methods are within 2% (high ΔP) to 7% (low ΔP) of each other.

10.2.2 BUILDING MATERIALS

As mentionned in IRC report (refer to Appendix "C"): "Figures 26 to 28 clearly show that for each of the three boards, the equation given by AIR-INS Inc. is very representative of the test specimens. The measurements at IRC show the inhomogeneity of each part of a given board. In each case, the AIR-INS Inc. equations give the dependence of air flow rate on the pressure difference well within the scatter due to the inhomogeneity. The average of IRC data cannot be expected to be identical to the value given by the AIR-INS Inc. equations because at IRC, though nine specimens were tested, the sampling allowed only 10% of the total area of the board to be tested. In spite of this limitation, when the inhomogeneity of the material is considered, the agreement between the measurements carried out at IRC and AIR-INS Inc. is very good".

10.2.3 CONCLUSION

In general the results from IRC and AIR-INS Inc. are very close to each other. Of all the measurements made by IRC and AIR-INS Inc., if there is any discrepancy, it is the results on orifice plate no.2. This discrepancy may very well be due to the fact that the attempted measurements were marginally outside the scope of the test set-up at IRC, especially limited to the orifice size of the specimen.

10.3 APPLICATION OF TEST METHOD

10.3.1 AIR LEAKAGE THROUGH THE TEST APPARATUS

To maintain confidence on the air permeance measurement for a specimen, it is essential that the test apparatus leakage (Q_L) be kept to a minimum. It should also be much lower than the air flow rate through the specimen (Q_S). Minimizing the air leakage (Q_L) was accomplished by sealing all joints of the test apparatus including pipe joints leading to the flow measuring devices.

The system leakage (Q_L) was kept below 50% for specimens having a low air permeance (Q_S 0.05 L/S-m^2) and below 10% for specimen having a high permeance (Q_S 0.05 L/S-m^2).

Table 10 shows typical ratio of Q_L/Q_S at 75 Pa. The air leakage through the test apparatus has been kept between 0.01 and 0.02 L/S for all specimens.

10.3.2 TIME REQUIRED TO REACH STEADY STATE

The time required to reach steady state (i.e. no variation of the pressure differential across the specimen with respect to time) is certainly a criterion of importance to define the total testing time. For a given change in flow rate (Q), let's simply say that the response time is a function of the system's volume (V), the volumetric flow rate of air (Q) and the type of flow regime (laminar, turbulent or combined).

TABLE 10: Q_L/Q_S AT P = 75 Pa

SPECIMEN NO.	Q_S at 75 Pa ($L/S-m^2$)	Q_L/Q_S at P = 75 Pa
18A	0.0192	0.929
18B	0.0047	2.17
15C	0.0101	0.997
20B	0.0093	1.20
22A	0.0151	0.888
6A	0.0199	0.495
14C	0.0198	0.508
23C	0.0387	0.390
23D	0.0205	0.461
30A	0.1385	0.083
30C	0.0243	0.403
11A	0.1860	0.08
10B	0.3914	0.054
24A	0.8426	0.018
1B	0.9095	0.017
2D	2.7312	0.004
29C	11.7338	0.001
7B	84.9493	0.0001

The longest response time will occur when one wants to determine the test apparatus leakage Q_L = 0.01 to 0.02 L/S at a specific ΔP. Since Q_L must be very small and the system's volume (V) V = 0.325 m^3 is a constant, the time required to reach steady state to get a single pair of data (Q and ΔP) may be a matter of hours (1 to 2 hours). If the specimen also shows a low air permeability (Q_S), the time required to reach steady state to get a single pair of data may also be one hour. Therefore, the determination of Q_S versus ΔP may require two days for low permeance materials and one day for high permeance materials. The only way to reduce the total testing time would be to decrease the system's volume (V).

10.4 BUILDING MATERIALS TEST RESULTS

10.4.1 INHOMOGENEITY WITHIN A GIVEN BOARD OR SHEET OF MATERIAL

Figures 26 to 28 from IRC test report show that for some materials, air permeance varies by as much as 30% to 50% from the average permeance. These variations are not caused by erroneous data but rather by inhomogeneity of the material under investigation.

10.4.2 INHOMOGENEITY OF A MATERIAL FROM ONE BOARD TO ANOTHER

Figure no. 29 gives the air flow rate (Q_S) versus ΔP for five specimens of a typical material (expanded polystyrene - type 2). Specimens 30A and 30B were made from the same board, the same applies to specimens 30C and 30D. Test results show that the air permeance of a material may vary from one board to another and that these variations can be very high. Another material which showed similar results is the 8mm plywood sheathing.

10.4.3 NUMBER OF TEST SPECIMENS TO BE TESTED

To verify the repeatability of the manufacturing process, specimens should be selected using the following criteria:

- one specimen per board or per roll;
- a minimum number of three (3) specimens should be tested to determine the air permeance of a material. This minimum number of specimens applies only when the minimum and maximum permeances are within 10% of the average permeance. If variations are higher than 10%, the number of specimens to be tested should be increased. Table 11 suggests an approach to determine the number of specimens.

TABLE 11: NUMBER OF SPECIMENS TO BE TESTED

NUMBER OF SPECIMENS	MAXIMUM VARIATION OF AIR PERMEANCE WITH RESPECT TO THE AVERAGE PERMEANCE (75 Pa)
3	± 10%
5	± 15%
7	± 20%
10	± 25%

10.4.4 CLASSIFICATION OF BUILDING MATERIALS

So far, nobody has put forth a method of classifying building materials by their air permeance. The only existing method of classification is given by IRC and is applicable to air barrier systems. Table 8 gives the rating of all materials which showed a measurable air flow rate.

It is beyond the scope of this study to establish a method to rate the air permeance of a material. Because of the numerous variables to consider, it will be left aside for a future study.

10.4.5 MODE OF AIR FLOW THROUGH BUILDING MATERIALS

The mode of air flow through classified building materials is given by the exponent "n" in the equation $Q = K\,(\Delta P)^n$. Table 8 shows that for classified materials the exponent "n" varies from 0.95 to 1.0. This suggests that the mode of air flow is mainly laminar (as expected).

Accepting the fact that $n = 1$, it will not be necessary in the future to measure the air permeance of building materials at several pressure differentials. A single air permeance value measured at a pressure differential of 75 Pa or 100 Pa could be used to calculate the air flow through a material at other pressure differentials.

Furthermore, the above simplification will allow designers to compute the air permeance (or resistance) of assemblies of materials (series or parrallel arrangement). Then, the approach taken to determine the resistance to air flow for an assembly of materials would be similar to analysing heat flow through walls.

11. GENERAL CONCLUSIONS

- The air permeance of building materials is a basic variable of concern in making an effective air barrier system. The determination of air permeance made by the present study will certainly prove to be helpful in the selection of materials to build a good air barrier system.

- The test method developed by the present study is in close agreement with the test method developed by IRC. This was demonstrated by the validation process.

- The test method may be applied to rigid (sheathing), flexible and loose materials, regardless of dimensions (length, width and thickness).

- The test method has been shown to be capable of measuring air flow rates with reasonnable accuracies at 1/10 of the suggested flow rate for a type 3 air barrier system and at 200 times the maximum suggested flow rate for a type 1 air barrier system.

- The study confirmed that at pressure differentials of 25 to 100 Pa the air flow regime through building materials is mainly laminar. Therefore, the evaluation of air flow resistance through a composite system can be calculated in the same manner as the resistance to heat or the resistance to current flow.

APPENDIX "A"

DETAILED PROCEDURE OF CALCULATION

TO DETERMINE THE AIR FLOW RATE

1. ACTUAL AIR FLOW RATE

The actual air flow rate (Q_{ACT}) through a laminar flow meter is determined by using of the related calibration curve and the measurement of the pressure differential (ΔP_{LF}) generated by air flow across the flow measuring device.

2. STANDARD AIR FLOW RATE

The standard air flow rate is calculated with the following relationship:

$$Q_{STD} = Q_{ACT} \times PCF \times TCF$$

Where:

Q_{STD} = Standard air flow rate (L/S)
Standard conditions are defined as:

$T_{STD} = 20°C = 293°K$
$P_{STD} = 101.3$ kPa

Q_{ACT} = Actual air flow rate (L/S)
PCF = Pressure correction factor.

$$PCF = \frac{(P_{BAR.ACTUAL} - P_{UPSTREAM\ ACTUAL})}{P_{STD}}$$

$P_{BAR.\ ACTUAL}$ = Barometric pressure measured while test is conducted (kPa).

$P_{UPSTREAM\ ACTUAL}$ = Pressure differential measured between the inlet of flow measuring device and the barometric pressure (kPa) in the laboratory.

TCF = Temperature and viscosity correction factor

$$TCF = \frac{T_{STD}\ (°K)}{273 + T_{UPSTREAM\ ACTUAL}} \quad \frac{x\ 187.87}{\mu\ air}$$

$T_{UPSTREAM\ \ ACTUAL}$ = Air temperature measured at the inlet of the flow measuring device (°C).

μ_{AIR} = Air viscosity at $T_{UPSTREAM\ ACTUAL}$ (micropoises).

APPENDIX "B"

ERROR ANALYSIS

B.1 SOURCES OF ERRORS

B.2 ALGORITHM FOR EVALUATION OF SYSTEMATIC ERRORS

B.3 EVALUATION OF THE PROPAGATION OF ERROR

B.4 VALUE OF THE ERROR ON THE AIR FLOW THROUGHT EACH MATERIAL

MEASURED VALUE	METHOD OR INSTRUMENT USED FOR MEASUREMENT	ACCURACY OR ERROR
Actual Flow	Meriam Flow Element Model 50MJ10-1/2 type 14	± 0.5% of the reading
Actual Flow	Meriam Flow Element Model 50MJ10-1/2 type 13	± 0.5% of the reading
Actual Flow	Meriam Flow Element Model 50MH10-1-NT	± 0.5% of the reading
Actual Flow	Meriam Flow Element Model 50MW20-2	± 0.5% of the reading
ΔP laminar flowmeter	Micromanometer "AIR Ltd" Model MP6KD	± 1.0% ± one count
P upstream	Micromanometer "AIR Ltd" Model MP6KD	± 1.0% ± one count
ΔP specimen	Micromanometer "AIR Ltd" Model MP3KDS	± 1.0% ± one count
Barometric pressure	Environment Canada (Montreal Weather office)	± 0.5%
T° upstream	Chromel-alumel thermocouple with digital readout	± 0.25% ± 1.8%/T°
Specimen width	Calibrated template error account for installation misfits	± 4 mm on the width
Specimen length	Calibrated template error account for instalation misfits	± 4 mm on the length

1. SYSTEMATIC ERRORS

The systematic errors are:

E_{QSTD} = the percentage of error on the standard air flow rate measurement.

E_{AREA} = the percentage of error on the measurement of the specimen effective area

$E_{\Delta P}$ = the percentage of error on the measurement of the pressure differential sustained by the specimen

2. EVALUATION OF E_{QSTD}

As covered in appendix A the standard air flow rate is calculated with the following relationship:

$$Q_{STD} = Q_{ACT} \times PCF \times TCF$$

The maximum percentage of error E_{QSTD} on Q_{STD} will be given by:

$$E_{QSTD} = E_{QLF} + E_{\Delta PLF} + E_{PCF} + E_{TCF}$$

Where:

E_{QLF} = Accuracy of the laminar flowmeter, which is equal to 0.5%

$E_{\Delta PLF}$ = Percentage of error on the measurement of pressure differential across the flowmeter

$$E_{PCF} = \left[\frac{P_{BAR} - P_{UP}}{P_{BAR} + P_{UP}}\right]\left[\left[\frac{P_{BAR}}{P_{BAR} + P_{UP}}\right] E_{PBAR} + \left[\frac{P_{UP}}{P_{BAR} + P_{UP}}\right] E_{PUP}\right]$$

Note: $P_{UP} = P_{UPSTREAM\ ACTUAL}$
$P_{BAR} = P_{BAR.\ ACTUAL}$
E_{PBAR} = Error on P_{BAR}
E_{PUP} = Error on P_{UP}

For the worst conditions $E_{PCF} = 0.5\%$

$$E_{TCF} = E_{TUP} + E_{\mu air}$$

Note: E_{TUP} = Error on T_{UP}
$T_{UP} = T_{UPSTREAM\ ACTUAL}$
$E_{\mu air}$ = Error on μ_{AIR}

For the worst conditions $E_{TCF} = 1.1\ \%$

Therefore, every measurement E_{QSTD} maximum is given by:

$$E_{QSTD} = E_{\Delta PLF} + 2.1\ \%$$

3. EVALUATION OF E_{AREA}

$$E_{AREA} = \left[\left[\frac{\text{Tolerance on the length}}{\text{Length}}\right] + \left[\frac{\text{Tolerance on the width}}{\text{Width}}\right]\right] \times 100$$

4. EVALUATION OF E_P

$$E_P = \left[1 + \frac{10}{\Delta P}\left[\left[\frac{P_{BAR.\ ACTUAL}}{P_{STD}} \times TCF\right]^{1/n} - 1\right]\right] \times 100$$

This error includes the inaccuracy on the measurement of ΔP across the specimen which is assumed to be at STP.

5. TOTAL SYSTEMATIC ERROR

The total systematic error E_{SFD} on the standard flow rate per unit area is given by:

$$E_{SFD} = E_{QSTD} + E_{AREA}$$

1. PROPAGATION OF ERROR

For the analysis of the propagation of error, the main report is well documented. Pleased refer to section 6.6.4 for further details.

MATERIAL		MAXIMUM PERCENTAGE OF ERROR AT 75 (Pa) (%)
NUMBER	DESCRIPTION	
1	Spunbonded Olefin	± 9.0
2	Perforated Polyethylene # 1	± 8.1
3	Perforated Polyethylene # 2	± 6.4
6	Non Perforated Reinforced Polyolefin	± 10.4
7	38 mm Cellulose Insulation	± 4.1
9	15 lb Asphalt Felt Non-Perforated	± 6.8
10	15 lb Asphalt Felt Air Vented	± 5.7
11	30 lb Roofing Felt	± 5.7
14	12.7 mm Gypsum board	± 12.7
15	12.7 mm Gypsum board M/R	± 29.4
16	3.2 mm Tempered Hard Board	± 11.7
17	Glass-wool Insulation	+ 139.5 ; -37.5
18	8 mm Plywood Sheathing	± 51.9
20	11.1 mm Wafer Board	± 20.8
21	15.9 mm Wafer Board	± 71.2
22	12.7 mm Particle Board	± 20.2
23	15.9 mm Particle Board	± 22.2
24	11.1 mm Fiberboard (Plain)	± 7.1
25	11.1 mm Fiberboard Asphalt coated	± 6.6
26	Tongue and Groove Planks	± 5.5
29	Expanded Polystyrene Type 1	± 8.4
30	Expanded Polystyrene Type 2	± 11.9
33	Fiberglass insulation (with spunbonded Polyolefin)	± 10.5
34	Vermiculite	± 54.0

Note: For all missing material there was no measurable flow.

APPENDIX "C"

VALIDATION OF TEST METHOD

C.1 Air-Ins Inc. results on orifice plates

C.2 IRC report on orifice plates .

C.3 Air-Ins Inc. results on building materials

C.4 IRC report on building materials

SPECIMEN NUMBER: PLATE No.1

MATERIAL NAME: PLATE No.1

AIR FLOW EQUATION "Q" ($L/S\text{-}m^2$)

Q_L (leakage) = 0.00103 x $P^{0.51973}$

Q_S (specimen) = 0.00108 x $P^{0.57299}$

STATIC PRESSURE DIFFERENTIAL ACROSS THE MATERIAL (Pa)	AIR FLOW RATE (avg) ($L/S\text{-}m^2$)	PERMEANCE (avg) (m/Pa-S)	RESISTANCE (avg) (Pa-S/m)
25	0,0069	2.7400×10^{-7}	3.6496×10^{6}
50	0,0102	2.0380×10^{-7}	4.9067×10^{6}
75	0,0129	1.7140×10^{-7}	5.8342×10^{6}
100	0.0152	1.5159×10^{-7}	6.5968×10^{6}

EQUIVALENT LEAKAGE AREA:

ELA = 1.63×10^{-6} m^2

Diam. ELA = 1.43916 mm

SPECIMEN NUMBER : PLATE No.2

MATERIAL NAME: PLATE No.2

AIR FLOW EQUATION "Q" (L/S-m^2)

Q_L (leakage) = 0.00091 x $P^{0.54334}$

Q_S (specimen) = 0.01595 x $P^{0.53499}$

STATIC PRESSURE DIFFERENTIAL ACROSS THE MATERIAL (Pa)	AIR FLOW RATE (avg) (L/S-m^2)	PERMEANCE (avg) (m/Pa-S)	RESISTANCE (avg) (Pa-S/m)
25	0,0893	3.5706×10^{-6}	2.80066×10^{5}
50	0,1293	2.5868×10^{-6}	3.86582×10^{5}
75	0,1607	2.1423×10^{-6}	4.66795×10^{5}
100	0,1874	1.8740×10^{-6}	5.33610×10^{5}

EQUIVALENT LEAKAGE AREA:

ELA = 2.19×10^{-5} m^2

Diam. ELA = 5.28644 mm

SPECIMEN NUMBER : PLATE No.3

MATERIAL NAME: PLATE No.3

AIR FLOW EQUATION "Q" ($L/S\text{-}m^2$)

Q_L (leakage) = 0.000843 x $P^{0.55825}$

Q_S (specimen) = 0.31564 x $P^{0.51866}$

STATIC PRESSURE DIFFERENTIAL ACROSS THE MATERIAL (Pa)	AIR FLOW RATE (avg) ($L/S\text{-}m^2$)	PERMEANCE (avg) (m/Pa-S)	RESISTANCE (avg) (Pa-S/m)
25	1,6759	6.7037×10^{-5}	1.49171×10^{4}
50	2,4010	4.8020×10^{-5}	2.08248×10^{4}
75	2,9629	4.9506×10^{-5}	2.53128×10^{4}
100	3,4397	3.4397×10^{-5}	2.90722×10^{4}

EQUIVALENT LEAKAGE AREA:

ELA = 4.18×10^{-4} m^2

Diam. ELA = 23.07814 mm

SPECIMEN NUMBER : PLATE No.4

MATERIAL NAME: PLATE No.4

AIR FLOW EQUATION "Q" ($L/S\text{-}m^2$)

Q_L (leakage) = 0.00093 x $P^{0.53763}$

Q_S (specimen) = 1.65554 x $P^{0.50064}$

STATIC PRESSURE DIFFERENTIAL ACROSS THE MATERIAL (Pa)	AIR FLOW RATE (avg) ($L/S\text{-}m^2$)	PERMEANCE (avg) (m/Pa-S)	RESISTANCE (avg) (Pa-S/m)
25	8,2947	3.3179×10^{-4}	3.01397×10^{3}
50	11,7357	2.3471×10^{-4}	4.26051×10^{3}
75	14,3769	1.9169×10^{-4}	5.21670×10^{3}
100	16,6041	1.6604×10^{-4}	6.02262×10^{3}

EQUIVALENT LEAKAGE AREA:

ELA = 2.10×10^{-3} m^2

Diam. ELA = 51.76790 mm

National Research Council Canada
Conseil national de recherches Canada

Institute for Research in Construction
Institut de recherche en construction

CLIENT REPORT

for

Air-Ins Inc., 2217 Guenette, Ville St-Laurent, Quebec H4R 2E9

Tests on "Orifice Plates" to Determine the Rates of Air Flow at Various Pressure Differences

Author
J.G. Theriault

Approved
R.P. Bowen
Section Head

Approved
W.A. Dalgliesh
Head, Quality Assurance

Report No: CR5666.1
Report date: 11 March 1988
Contract No. CR5666
Reference: Application for test dated 29 January 1988
Section: Building Performance

7 pages
Copy No. 1 of 5 copies

Rate of air flow through orifice plates at various pressure differences

Introduction:

The measurements reported here were aimed at a comparison of the test facilities at Air-Ins Inc. and the Institute for Research in Construction that are used for the determination air flow resistances of various building materials. The test facility at Air-Ins Inc. accommodates test specimens with an area of 1 m^2 whereas at IRC the area of the test specimen is 1.23×10^{-2} m^2.

Though there is a large difference in the sizes of the test specimens, it is expected that the present investigation will help to verify the precision of the testing equipment at Air-Ins Inc.

Material:

The material used in this test was received from the applicant on 4 February 1988. It consisted of four aluminum plates measuring 30.5 cm x 30.5 cm and 1.6 mm thick. In the centre of each plate, one or more holes had been drilled. The plates were identified by the applicant as follows:

Plate No. 1: Orifice nominal diameter: 3/64 in. (1 hole)
Plate No. 2: Orifice nominal diameter: 13/64 in. (1 hole)
Plate No. 3: Orifice nominal diameter: 7/8 in. (1 hole)
Plate No. 4: Orifice nominal diameter: 1 in. (4 holes)

The direction of flow was also indicated on each plate.

Preparation of specimens: A circular specimen was cut 125 mm in diameter from the centre of Plates No. 1 and No. 2. These orifice discs were then sealed in plexiglas rings of the same diameter with RTV silicone rubber. Plates No. 3 and No. 4 were not tested since the size of the hole(s) was much larger than can be accommodated by the experimental set-up at IRC.

Measurement:
The experimental set-up used for the investigation is schematically shown in Figure 1. This method is similar to the test method reported in the Building Research Note No. 227, enclosed herewith, except that the location at which the pressure difference is measured is different. The present set-up can accommodate higher air flow rates than was originally intended during the development of the test method reported in the Building Research Note.

Results:

The results from measurements on Plate No. 1 and Plate No. 2 are given in Tables 1 and 2. Also given in the table are air flow rates calculated according to the flow-equation given by Air-Ins Inc.

For Plate No. 1 the root mean square deviation of the experimental data from the Air-Ins Inc. flow equation is 0.0002 ℓ/s and for Plate No. 2, 0.007 ℓ/s.

The experimental data are plotted in Figures 2 and 3 and compared with the Air-Inc Inc. flow equations.

Conclusion:

For Plate No. 1, though the experimental values for the rate of flow are systematically higher than that given by the Air-Ins Inc. flow equation, the deviation is well within the accuracy of the test method.

For Plate No. 2, though the flow rates used are higher than what is usually encountered, the overall agreement between experimental values and those calculated from the Air-Ins Inc. flow equation is fair. In the pressure difference range, 50 to 100 Pa, the agreement is good.

Table 1: Experimental data on "Orifice Plate No.1, 3/64 inch hole", Q is the volumetric air flow rate and ΔP is the pressure difference at the steady state.

ΔP (Pa)	Q ($\ell.sec^{-1}$)	Q(Calculated)* ($\ell.sec^{-1}$)
3.9	0.00259	0.00242
5.9	0.00323	0.00306
11.0	0.00453	0.00436
16.6	0.00582	0.00550
30.8	0.00808	0.00779
49.0	0.01035	0.01013
60.7	0.01164	0.01143
73.9	0.01293	0.01278
92.0	0.01455	0.01446

* These values were calculated from the flow equation of Air-Ins Inc. data sheet provided.

Table 2: Experimental data on "Orifice Plate No.2, 13/64 inch hole", Q is the volumetric air flow rate and ΔP is the pressure difference at the steady state.

ΔP (Pa)	Q ($\ell.sec^{-1}$)	Q(Calculated)* ($\ell.sec^{-1}$)
6.9	0.0573	0.0459
9.8	0.0650	0.0551
13.7	0.0745	0.0657
15.7	0.0762	0.0706
15.7	0.0765	0.0706
20.6	0.0867	0.0814
31.3	0.1073	0.1014
34.3	0.1122	0.1064
48.0	0.1311	0.1269
63.6	0.1500	0.1471
82.2	0.1688	0.1683
104.8	0.1877	0.1912

* These values were calculated from the flow equation of Air-Ins Inc. data sheet provided.

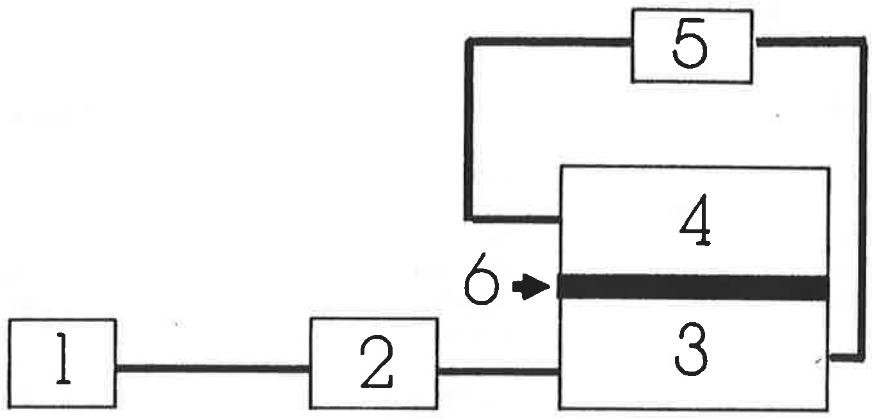


Figure 1

Schematic of the test assembly

1. compressed air & flow regulator
2. flowmeter
3. lower half of test chamber
4. upper half of test chamber
   (open to atmosphere)
5. manometer
6. test specimen

PLATE No. 1

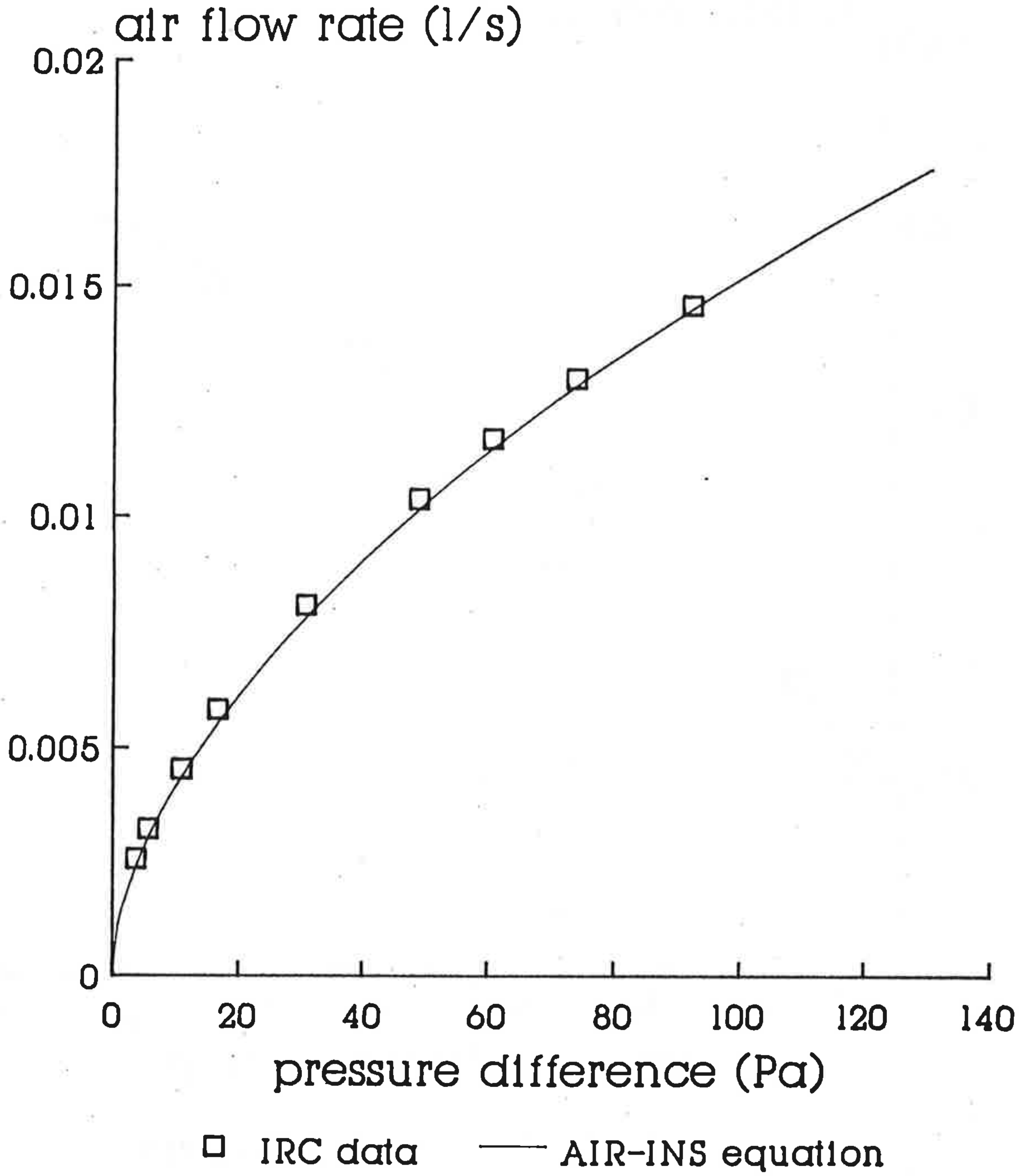


Figure 2

PLATE No. 2

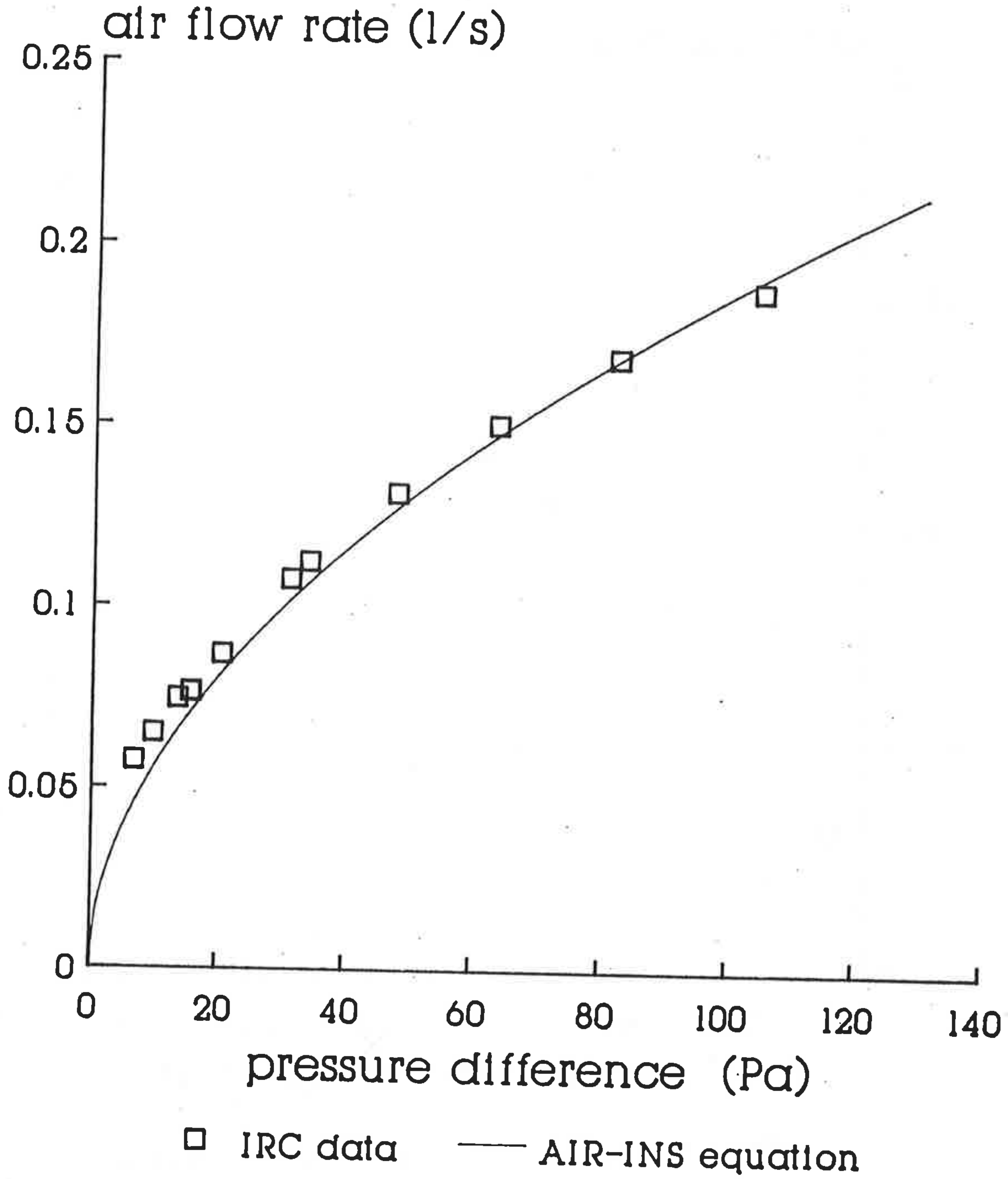


Figure 3

SPECIMEN NUMBER : 19A

MATERIAL NAME: TEMPERED HARDBOARD

AIR FLOW EQUATION "Q" $(L/S\text{-}m^2)$

Q_L (leakage) = 0.00083 x $P^{0.56266}$

Q_{LS} (leakage & specimen) = 0.00076 x $P^{0.85251}$

Q_S (specimen) = 0.00027 x $P^{1.000}$

STATIC PRESSURE DIFFERENTIAL ACROSS THE MATERIAL (Pa)	AIR FLOW RATE (avg) $(L/S\text{-}m^2)$	PERMEANCE (avg) (m/Pa-S)	RESISTANCE(avg) (Pa-S/m)
25	0,0068	2.7315×10^{-7}	3.66098×10^{6}
50	0,0137	2.7315×10^{-7}	3.66098×10^{6}
75	0,0205	2.7315×10^{-7}	3.66098×10^{6}
100	0.0273	2.7315×10^{-7}	3.66098×10^{6}

EQUIVALENT LEAKAGE AREA:

ELA = 1.097×10^{-6} m^2

Diam. ELA = 1.18161 mm

SPECIMEN NUMBER : 33E

MATERIAL NAME: EXPANDED POLYSTYRENE TYPE 1

AIR FLOW EQUATION "Q" (L/S-m²)

Q_L (leakage) = 0.00034 x $P^{0.748705}$

Q_{LS} (leakage & specimen) = 0.27699 x $P^{0.91129}$

Q^S (specimen) = 0.27668 x $P^{0.91141}$

STATIC PRESSURE DIFFERENTIAL ACROSS THE MATERIAL (Pa)	AIR FLOW RATE (avg) (L/S-m^2)	PERMEANCE (avg) (m/Pa-S)	RESISTANCE (avg) (Pa-S/m)
25	5,2007	2.0803×10^{-4}	4.80702×10^3
50	9,7819	1.9564×10^{-4}	5.11147×10^3
75	14,1551	1.8874×10^{-4}	5.29842×10^3
100	18,3986	1.8399×10^{-4}	5.43520×10^3

EQUIVALENT LEAKAGE AREA:

ELA = 9.058×10^{-4} m^2

Diam. ELA = 33.95947 mm

SPECIMEN NUMBER : 34A

MATERIAL NAME: EXPANDED POLYSTYRENE TYPE 2

AIR FLOW EQUATION "Q" (L/S-m²)

Q_L (leakage) = $0.00072 \times P^{0.64106}$

Q_{LS} (leakage & specimen) = $0.23453 \times P^{0.96352}$

Q^S (specimen) = $0.00188 \times P^{0.99554}$

STATIC PRESSURE DIFFERENTIAL ACROSS THE MATERIAL (Pa)	AIR FLOW RATE (avg) ($L/S\text{-}m^2$)	PERMEANCE (avg) (m/Pa-S)	RESISTANCE(avg) (Pa-S/m)
25	0,0464	1.8559×10^{-6}	5.38814×10^{5}
50	0,0925	1.8502×10^{-6}	5.40483×10^{5}
75	0,1385	1.8469×10^{-6}	5.41462×10^{5}
100	0,1844	1.8445×10^{-6}	5.42157×10^{5}

EQUIVALENT LEAKAGE AREA:

ELA = 7.481×10^{-6} m^2

Diam. ELA = 3.08631 mm

National Research Council Canada
Institute for Research in Construction

Conseil national de recherches Canada
Institut de recherche en construction

CLIENT REPORT

for

Air-Ins Inc., 2217 Guenette,
Ville St-Laurent, Quebec H4R 2E9

Tests on Tempered Hardboard and Expanded Polystyrene (Types 1 and 2) to Determine Rates of Air Flow at Various Pressure Differences

Author J.G. Theriault

Approved R.P. Bowen
Section Head

Approved W.A. Dalgliesh
Head, Quality Assurance

Report No: CR5666.2
Report date: 21 April 1988
Contract No. CR5666
Reference: Application for test dated 29 January 1988
Section: Building Performance

8 pages
Copy No. 1 of 5 copies

Canada

Rate of air flow through boards of building materials

Introduction

This is a continuation of test report CR5666.1 issued by the Institute for Research in Construction, on 11 March 1988. The tests reported earlier showed that reliable data on air flow rates through test specimens at various pressure differences can be obtained from the equipment at Air-Ins Inc.

The present measurements were organized as follows: Air-Ins Inc., after completion of their measurements on several specimens ($\approx 1m^2$ area) of building boards, selected three specimens and submitted them to IRC for further tests. The specimens were selected in such a way that their permeance differed widely and represented the least permeable, most permeable and an intermediate one, as established by Air-Ins Inc. measurements. At IRC each of the three specimens were subdivided into nine smaller specimens ($\approx 0.012m^2$ area) and tested. The objective of this exercise is to reassure the reliability of the test results obtained at Air-Ins Inc. on various building boards, irrespective of the flow rates used in the measurements.

Material Identification and Description

The material used in these tests was received on 22 March 1988. It consisted of three boards each measuring 1.1 m x 1.1 m. Two boards were 25 mm thick expanded polystyrene and the third, a tempered hardboard. The applicant had identified the boards as follows:

1. Tempered Hardboard 1/8" - Specimen 19A
2. 1" Expanded Polystyrene Type 1 - Specimen 33E
3. 1" Expanded Polystyrene Type 2 - Specimen 34A

The direction of flow was also indicated on the boards.

Preparation of Specimens: Each board was divided into nine equal squares. A circular specimen was cut 125 mm in diameter from the centre of each of these nine squares and sealed into a Plexiglas ring of the same diameter with RTV silicone rubber. Thus, nine test specimens were prepared from each board.

Measurement: The experimental set-up is identical to that summarized in report CR5666.1. The experimental results are given in Tables 1 to 3 and are plotted in Figures 1 to 3. Also plotted in the figures are the average of the experimental data and the values given by Air-Ins Inc. equation for each board; the average values were determined for each board through least-squares analysis of all nine sets of data, each data pair having been weighted equally.

Conclusion: Figures 1 to 3 clearly show that for each of the three boards the equation given by Air-Ins Inc. is very representative of the test specimen. The measurements at IRC show the inhomogeneity of each board. In each case Air-Ins Inc. equation gives the dependence of air flow rate on the pressure difference well within the scatter due to the inhomogeneity. The average of IRC data cannot be expected to be identical to the value given by Air-Ins Inc. equation because at IRC, though nine specimens are tested, the sampling allowed only 10% of the total area of the board to be tested. In spite of this limitation, when the inhomogeneity of the material is considered, the agreement between the measurements carried out at Air-Ins Inc. and IRC is very good.

In general the quality of the results from Air-Ins Inc. appears to be excellent. Of all the measurements done between Air-Ins Inc and IRC, if there is any discrepancy, it is in the results on the 13/64" orifice plate (report CR5666.1). That discrepancy may very well be due to the fact that the attempted measurement was marginally outside the scope of the test set-up at IRC, especially limited by the size of the test specimen.

Table 1 Experimental data on nine test specimens prepared from Air-Ins Inc. specimen number 19A, tempered hardboard; Q is volumetric air flow rate and Δp the corresponding pressure difference.

Δp (Pa)	Q {cm³/(m².s)}	Δp (Pa)	Q {cm³/(m².s)}	Δp (Pa)	Q {cm³/(m².s)}
Specimen #1		Specimen #2		Specimen #3	
33	8.9	42	8.7	49	8.7
42	13.7	57	13.5	66	13.4
59	17.8	66	17.5	85	17.4
67	21.2	87	20.8	109	20.7
73	25.6	112	25.1	121	25.0
Specimen #4		Specimen #5		Specimen #6	
63	8.8	40	8.9	22	8.9
95	13.6	65	13.8	31	13.7
123	17.6	85	17.9	46	17.9
134	21.0	95	21.3	54	21.2
152	25.3	106	25.7	63	25.7
				94	38.8
				130	54.0
Specimen #7		Specimen #8		Specimen #9	
29	8.8	34	8.6	46	8.6
44	13.5	55	13.2	66	13.3
56	17.6	74	17.2	90	17.3
63	20.9	82	20.4	100	20.6
72	25.3	93	24.7	118	24.9
101	38.2				

Table 2 Experimental data on nine test specimens prepared from Air-Ins Inc. specimen number 33E, expanded polystyrene type 1; Q is volumetric air flow rate and Δp the corresponding pressure difference.

Δp (Pa)	Q {$dm^3/(m^2.s)$}	Δp (Pa)	Q {$dm^3/(m^2.s)$}	Δp (Pa)	Q {$dm^3/(m^2.s)$}
Specimen #1		Specimen #2		Specimen #3	
15	3.0	15	3.6	18	3.7
25	4.9	25	6.2	25	5.0
49	9.6	36	9.0	37	7.7
74	13.7	49	12.0	49	9.9
98	17.6	61	14.4	67	13.3
113	20.1	74	17.2	74	14.3
		86	19.9	85	16.3
		98	22.0	98	18.5
				108	20.6
Specimen #4		Specimen #5		Specimen #6	
18	3.1	12	2.7	16	2.9
25	4.4	25	5.4	25	4.6
37	6.8	36	8.0	36	6.6
49	8.7	49	10.7	49	8.9
63	11.1	61	13.3	61	10.9
74	12.6	74	15.5	74	13.2
85	14.6	85	17.9	85	14.8
98	16.5	98	20.1	98	16.9
113	18.7	110	22.1	110	18.5
Specimen #7		Specimen #8		Specimen #9	
12	2.1	13	3.2	13	2.9
25	4.1	25	6.3	25	5.5
37	6.2	37	9.4	36	8.2
49	8.2	49	12.4	49	10.8
62	10.2	62	15.1	61	13.3
74	12.1	74	17.6	74	15.5
86	13.9	85	20.1	85	17.7
98	15.4	97	22.5	98	20.1
111	17.1			108	21.8

Table 3 Experimental data on nine test specimens prepared from Air-Ins Inc. specimen number 34A, expanded polystyrene type 2; Q is volumetric air flow rate and Δp the corresponding pressure difference.

Δp (Pa)	Q {$cm^3/(m^2.s)$}	Δp (Pa)	Q {$cm^3/(m^2.s)$}	Δp (Pa)	Q {$cm^3/(m^2.s)$}
Specimen #1		Specimen #2		Specimen #3	
11	25.8	12	25.8	12	26.0
27	62.8	35	62.8	32	63.4
56	128.7	66	128.7	63	129.8
75	187.3	91	187.3	85	189.0
165	381.6	193	381.6	181	385.0
Specimen #4		Specimen #5		Specimen #6	
13	25.8	15	25.8	17	25.8
36	62.8	42	62.8	43	62.8
68	128.7	82	128.7	89	128.7
94	187.3	113	187.3	120	187.3
198	381.6	239	381.6	262	381.6
Specimen #7		Specimen #8		Specimen #9	
11	25.6	7	26.0	7	26.2
28	62.3	18	63.4	18	63.9
57	127.6	36	129.8	36	131.0
75	185.7	48	189.0	48	190.6
165	378.4	106	385.0	106	388.3

SPECIMEN NUMBER 19A
TEMPERED HARDBOARD

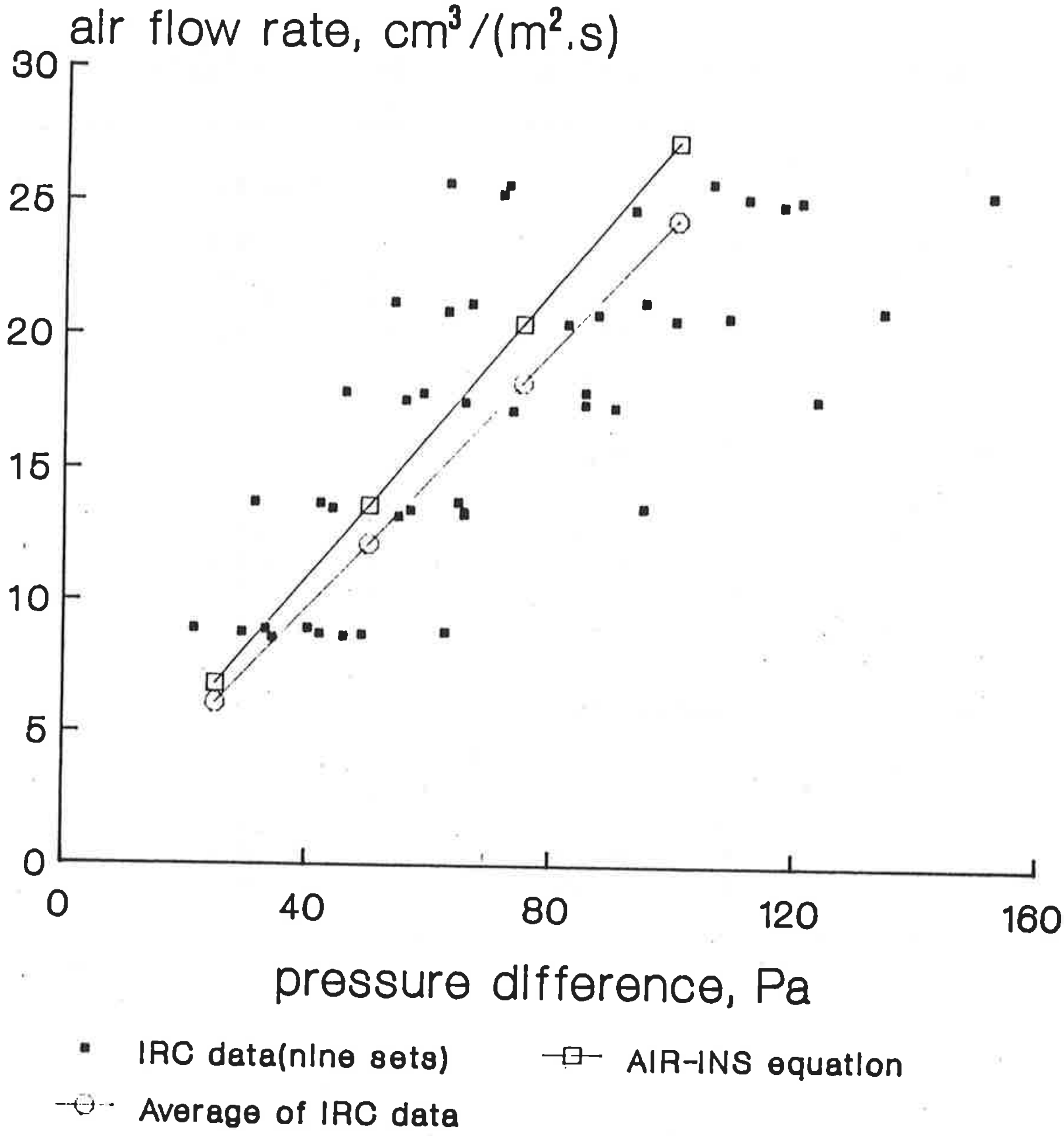


Figure 1

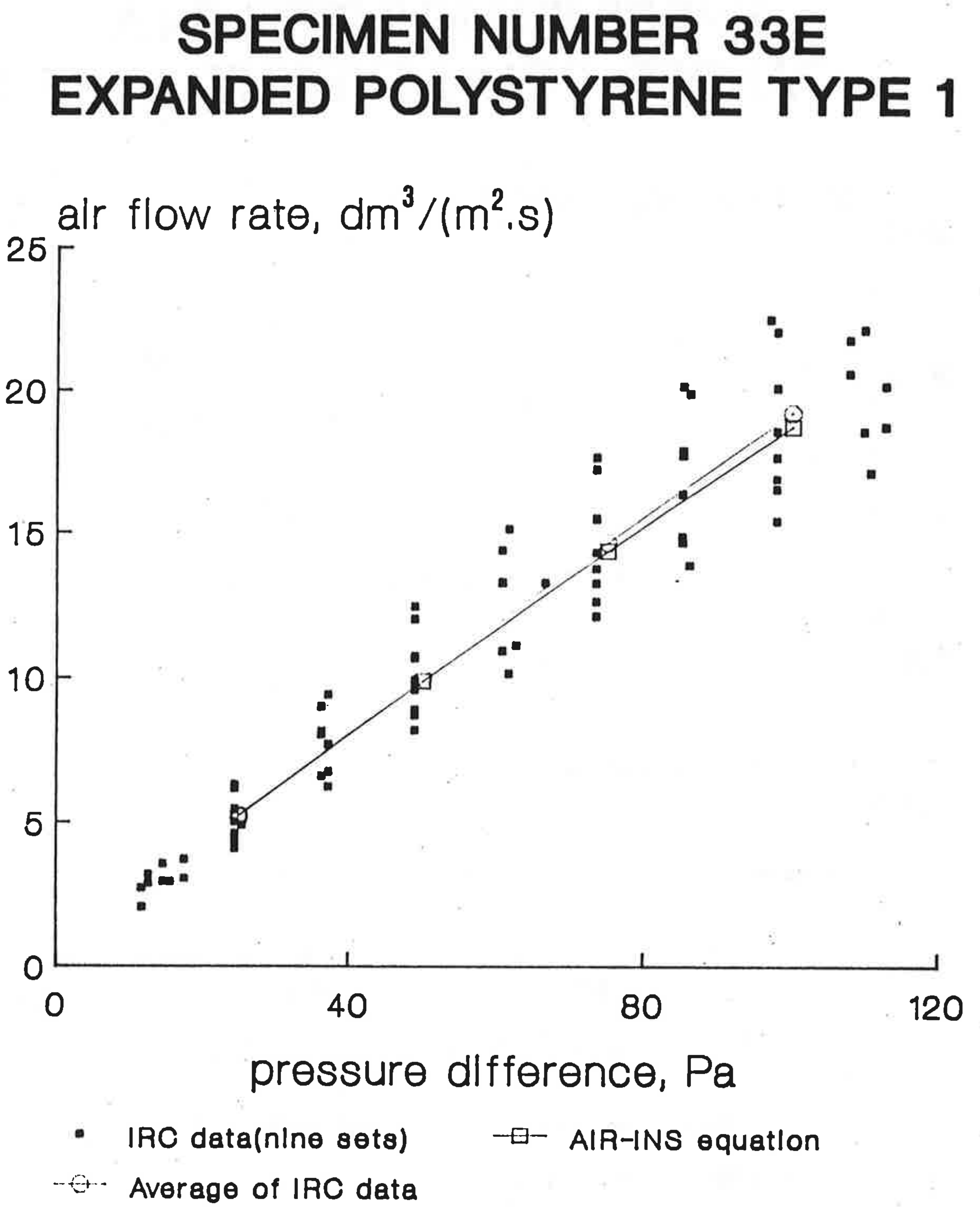

SPECIMEN NUMBER 33E
EXPANDED POLYSTYRENE TYPE 1
air flow rate, dm³/(m².s)
25
20
15
10
5
0
0
40
80
120
pressure difference, Pa
IRC data(nine sets)
AIR-INS equation
Average of IRC data

Figure 2

SPECIMEN NUMBER 34A
EXPANDED POLYSTYRENE TYPE 2

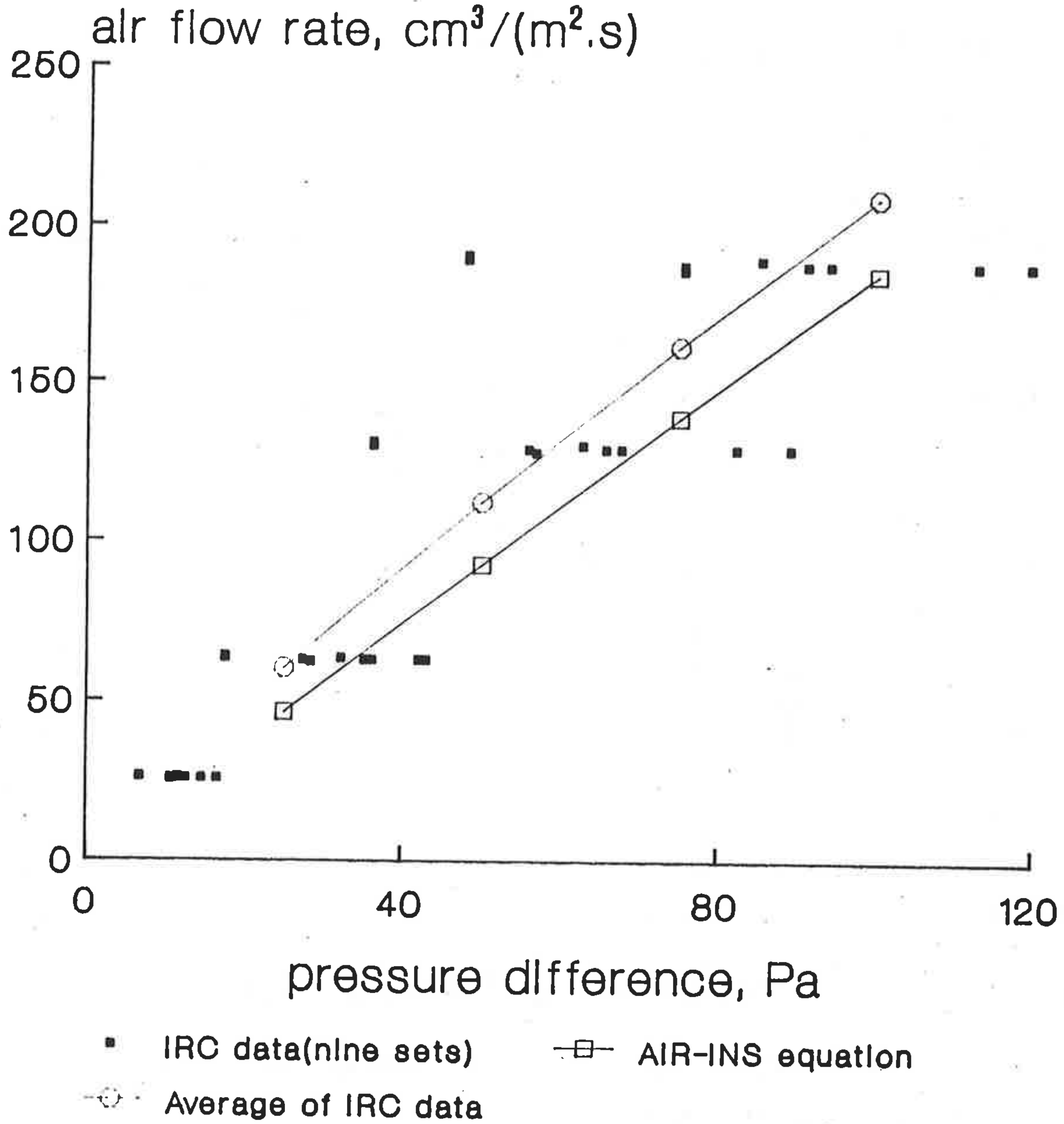


Figure 3

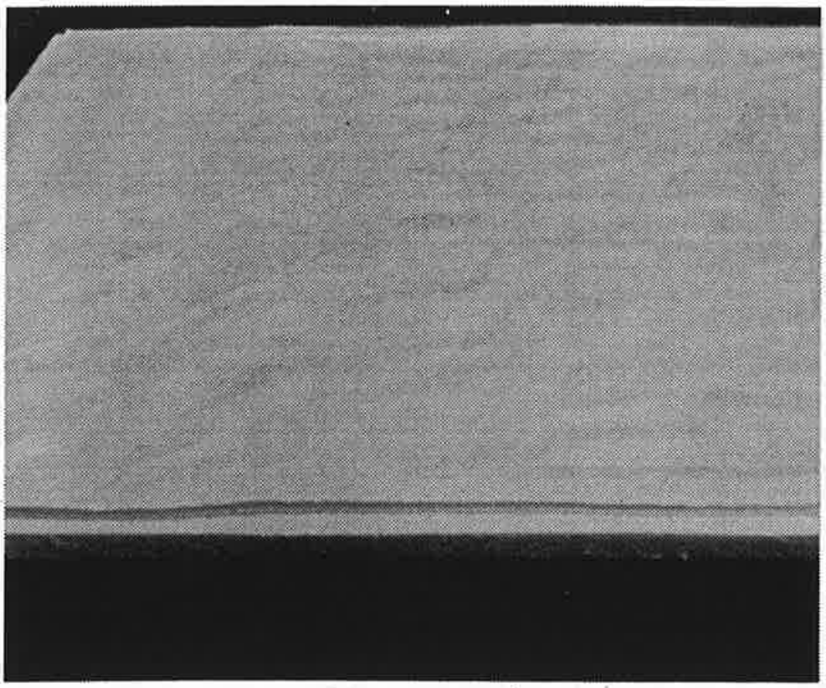
APPENDIX "D"

DESCRIPTION OF BUILDING MATERIALS

Material No 1

Description: Spunbonded Olefin film.

Thickness: 3 mils



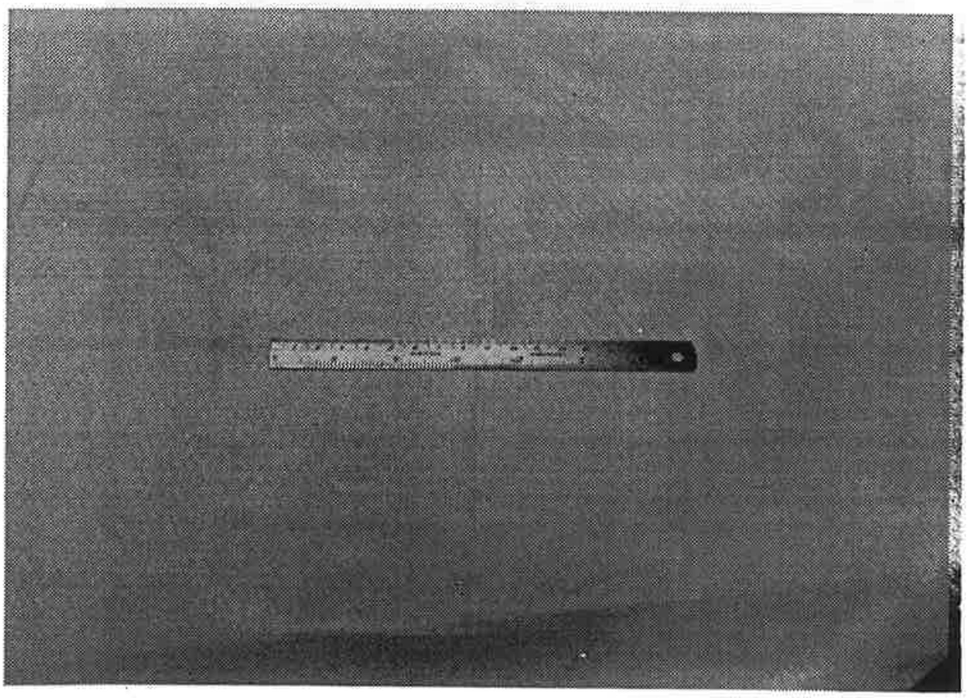
Photograph No.: D-1

Material No. 2

Description: Perforated polyethylene film no. 1.

Thickness : 3 mils

Caractheristic: 4.3 perforations per cm^2



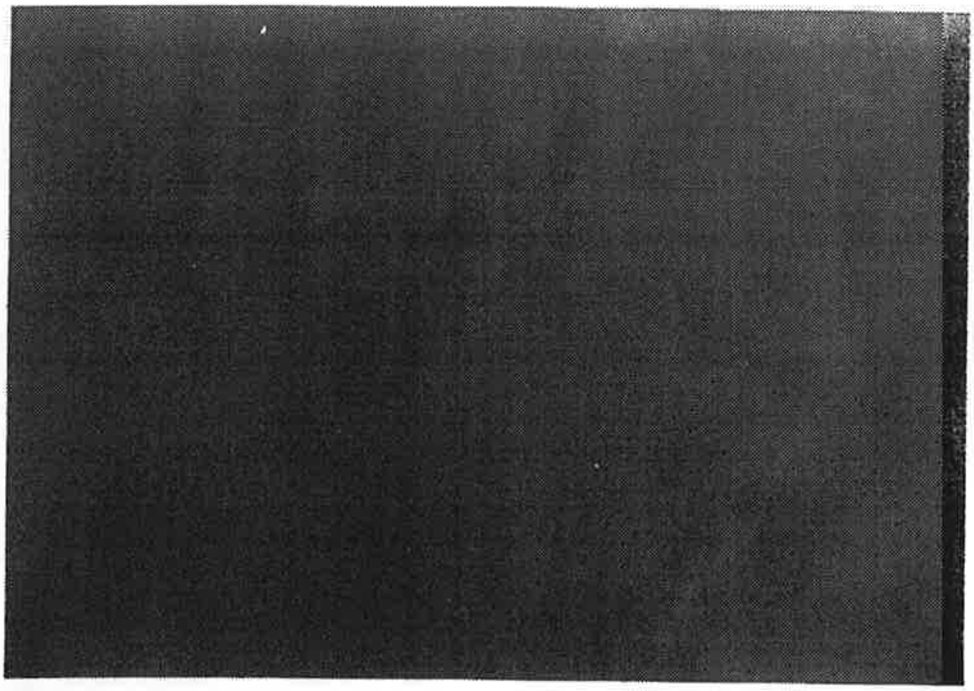
Photograph no.: D-2

Material No. 3

Description: Perforated polyethylene film no. 2.

Thickness: 3 mils

Caractheristic: 4.5 perforations per cm^2.

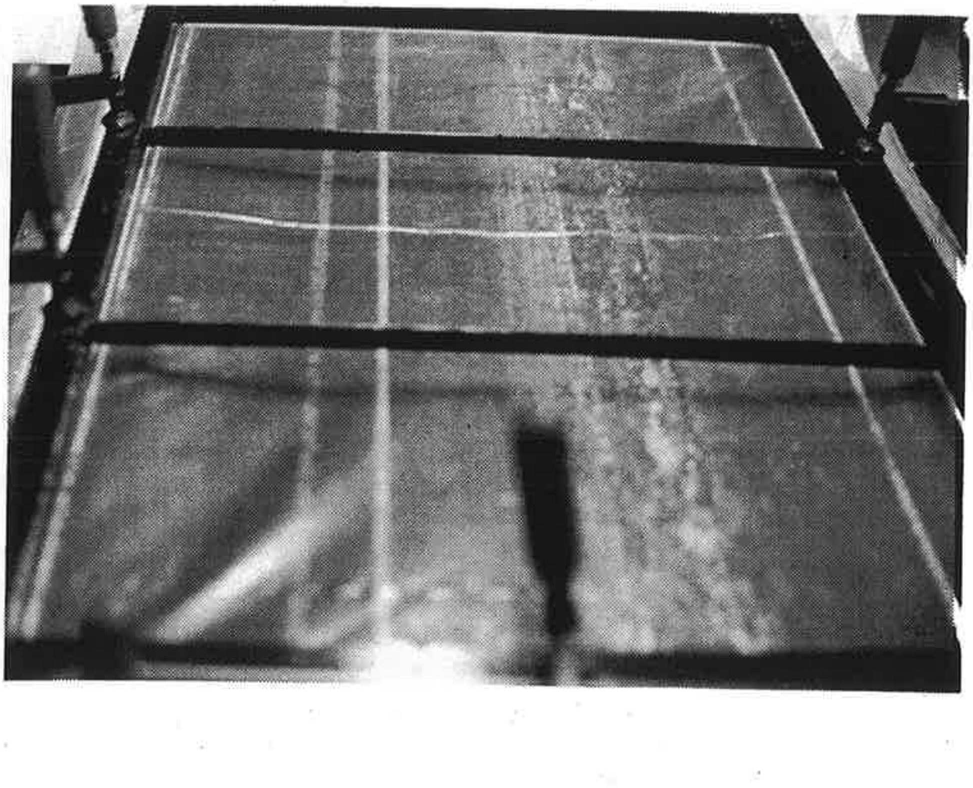


Photograph No.: D-3

Material No. 4

Description: Smooth surface roofing bituminous membrane.

Thickness: 2 mm



Photograph No.: D-4

Material No. 5

Description: Modified bituminous torch on grade membrane produced by coating a glass fiber mat with and SBS modified asphalt and a thermofusible film on both surfaces of the mat.

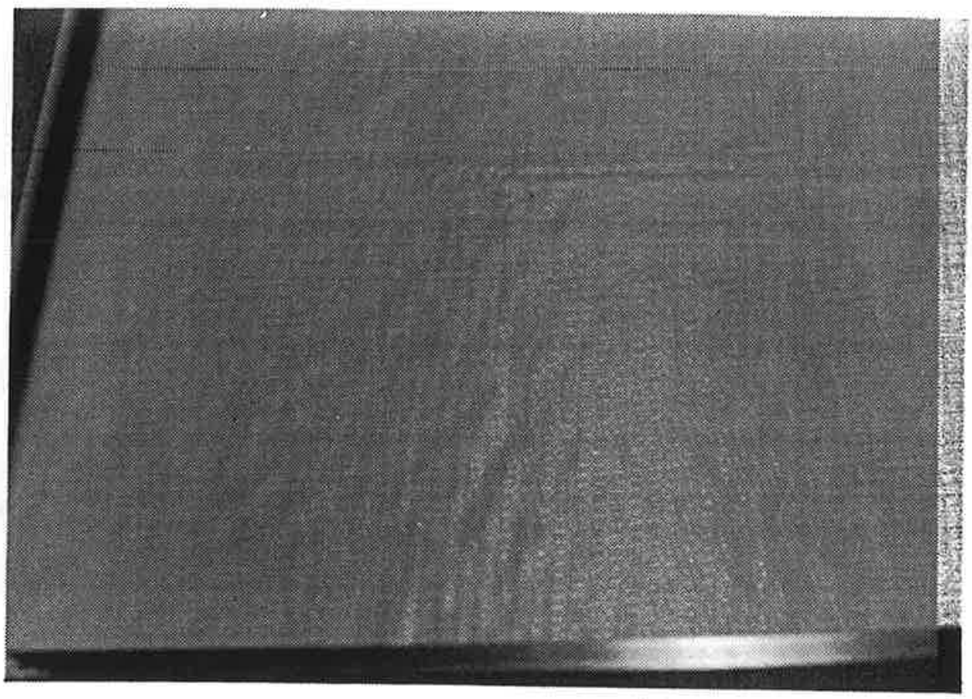
Thickness: 2.7 mm

Photograph No.: D-5

Material No. 6

Description: Reinforced non perforated polyolefin film.

Thickness: 4 mils

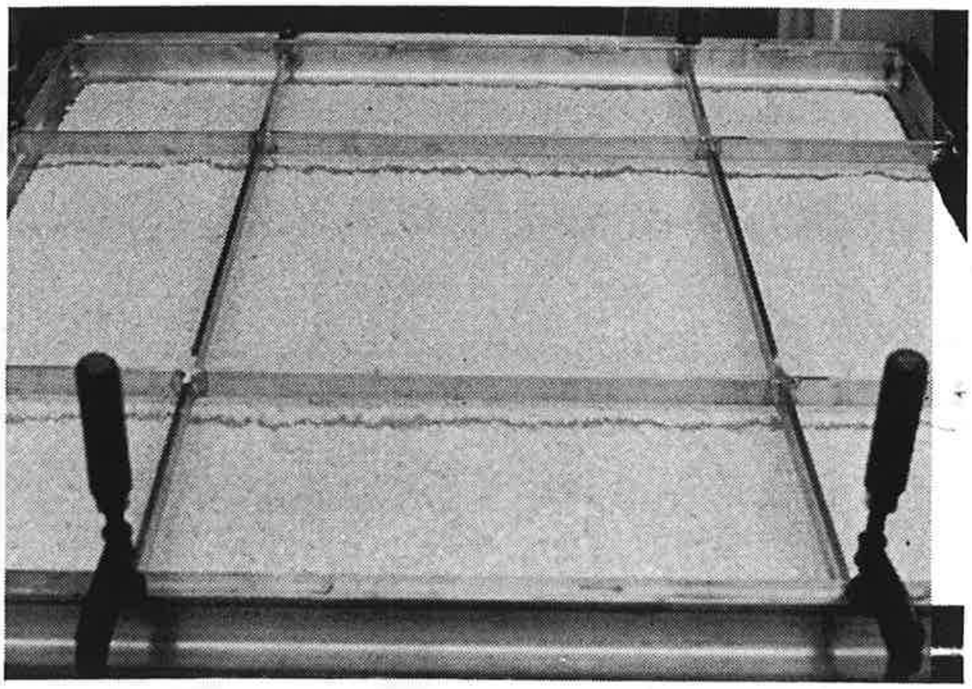


Photograph No.: D-6

Material No. 7

Description: Specially prepared chemically treated hollow cellulose fibre spray on insulation.

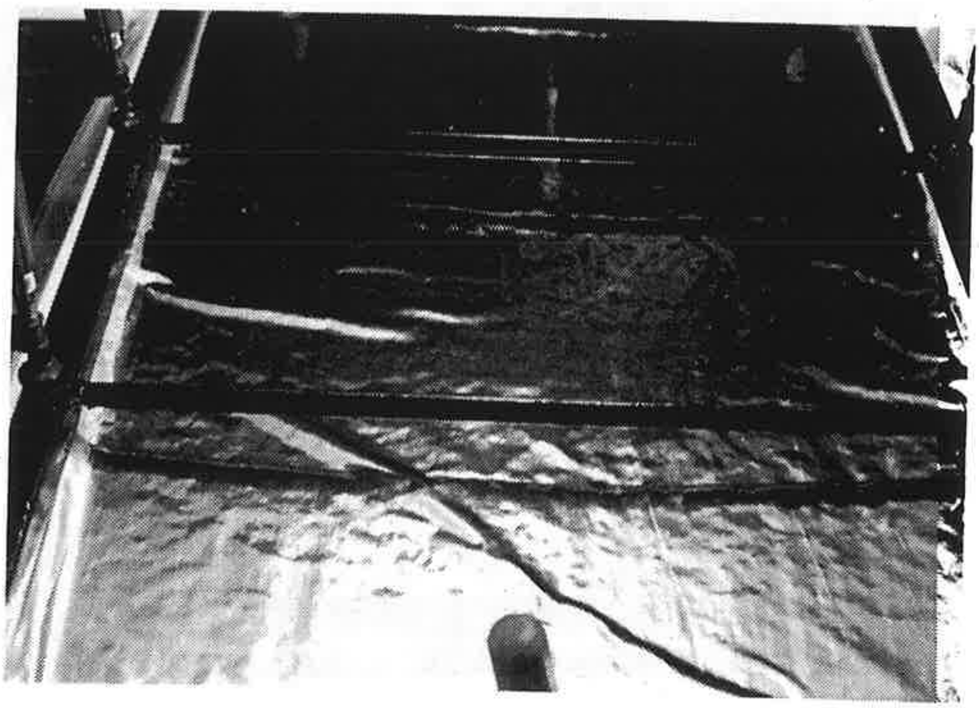
Thickness: 38 mm



Photograph No.:D-7

Material No. 8

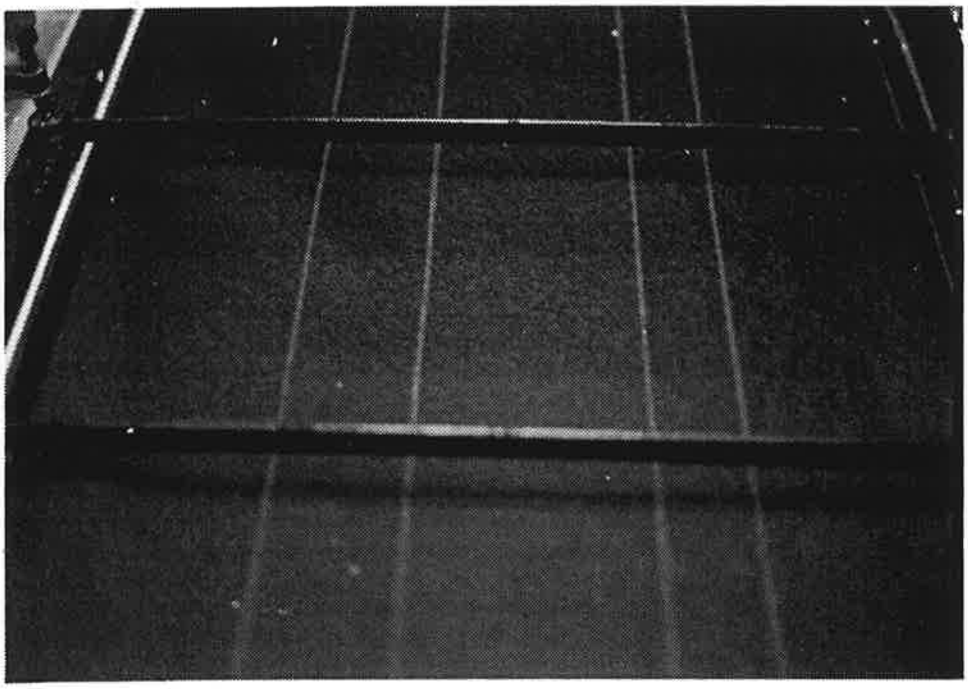
Description: Reflective vapour barrier (95% reflective aluminum foil on kraft paper).



Photograph No.: D-8

Material No. 9

Description: 15 lb non-perforated asphalt felt

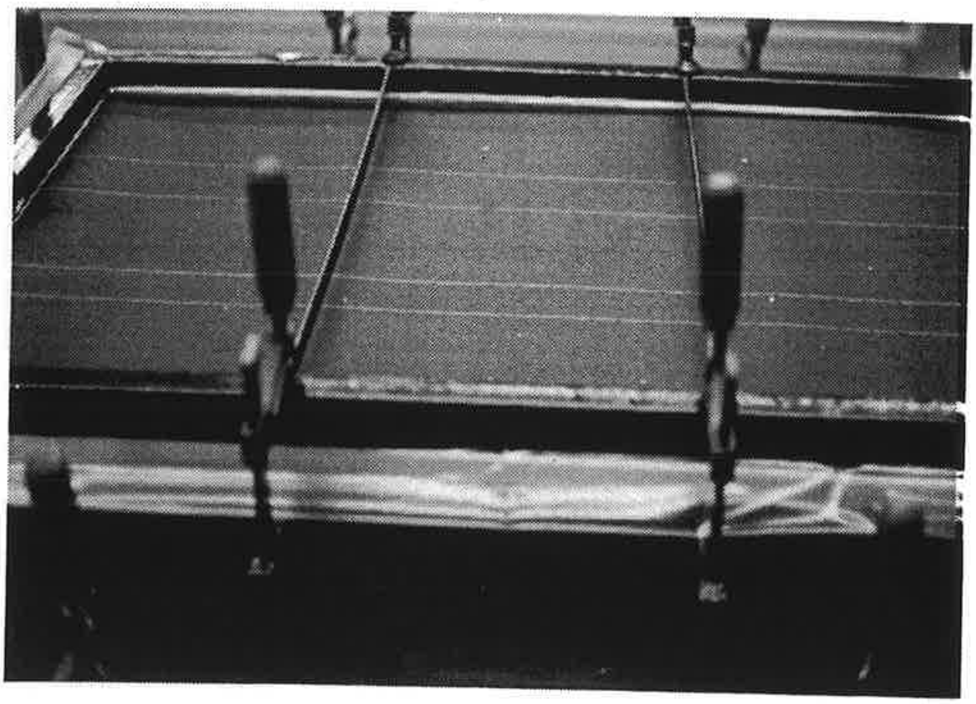


Photograph No.: D-9

Material No. 10

Description: 15 lb asphalt felt with air vents

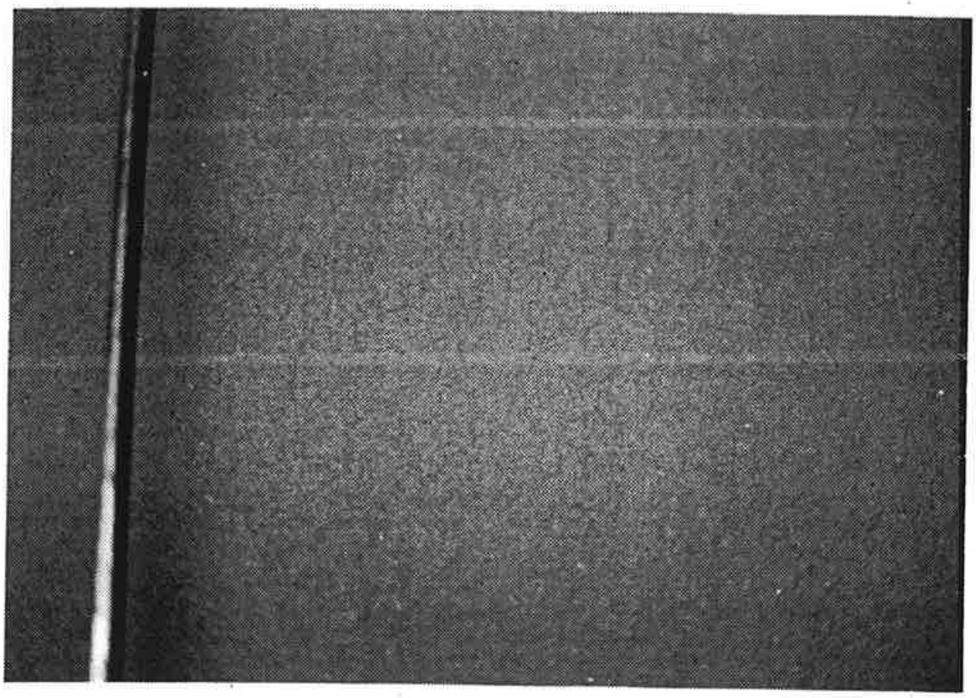
Caracteristic: 0,3 perforations per cm^2



Photograph No.: D-10

Material No. 11

Description: 30 lb saturated roofing felt.

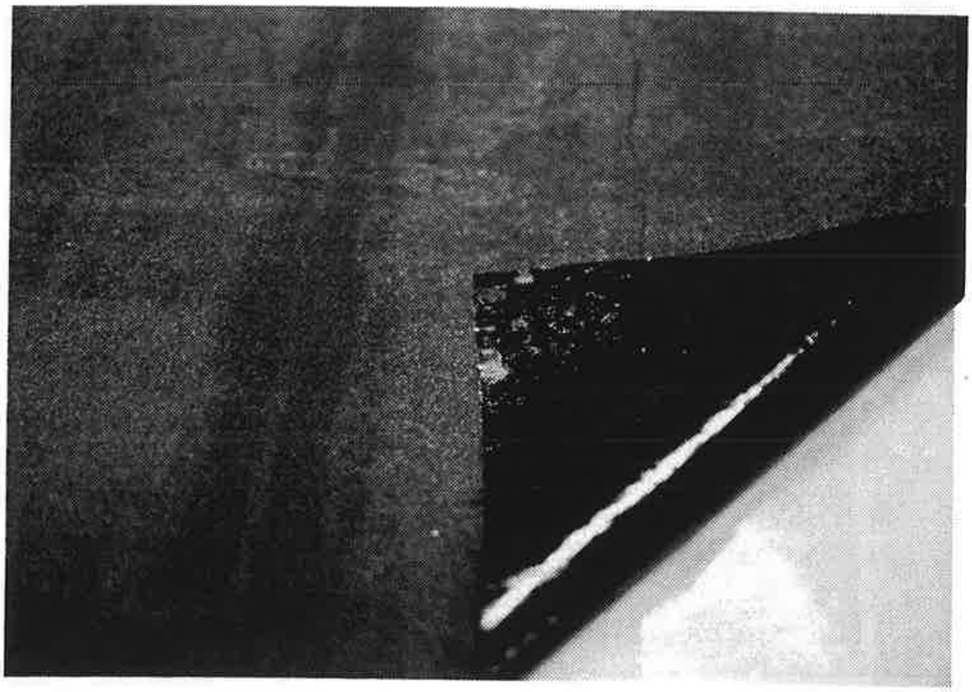


Photograph No.: D-11

Material No. 12

Description: Modified bituminous self-adhesive membrane produced by coating a glass fiber reinforcing mat with SBS modified asphalt.

Thickness: 1.3 mm

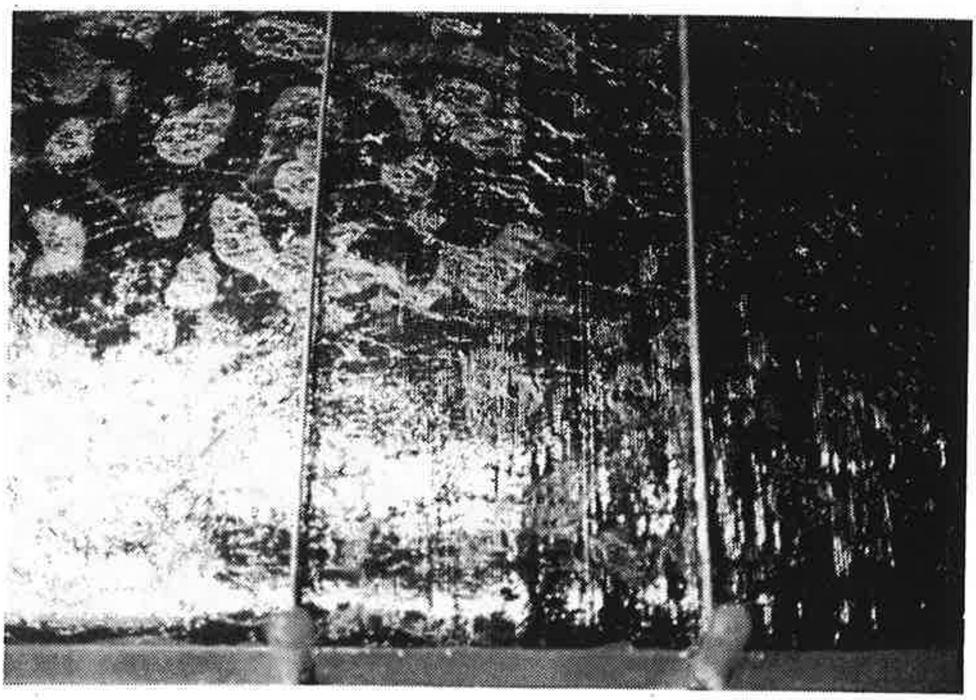


Photograph No.: D-12

Material No. 13

Description: Modified bituminous torch on grade membrane produced by coating a polyester reinforcing mat with an SBS modified asphalt an a thermofusible film on both surfaces of the film.

Thickness: 2.7 mm

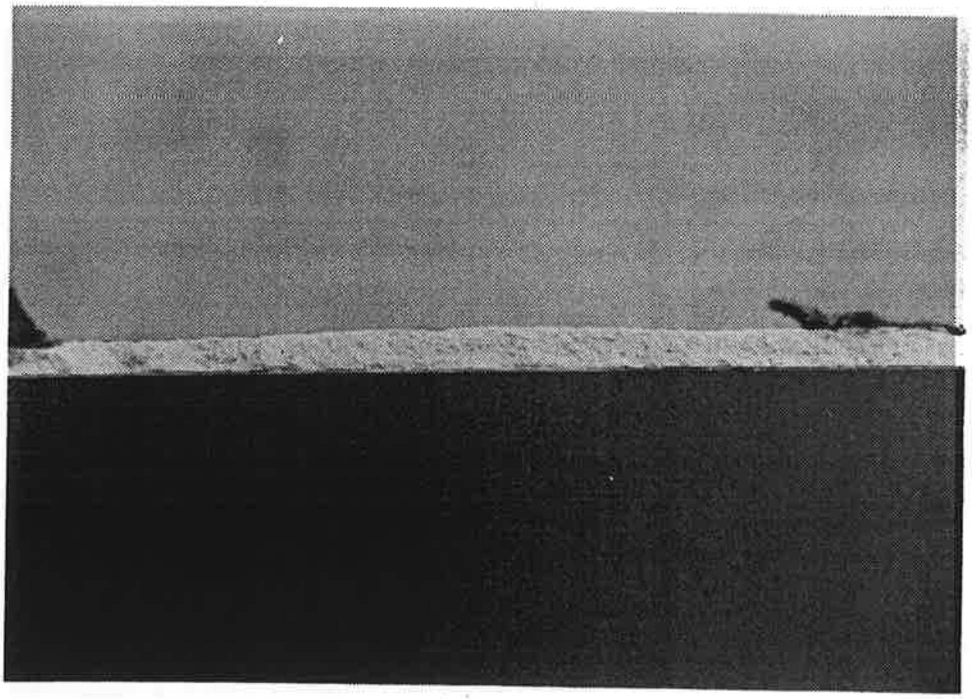


Photograph No.: D-13

Material No. 14

Description: Gypsum board.

Thickness: 12.7 mm

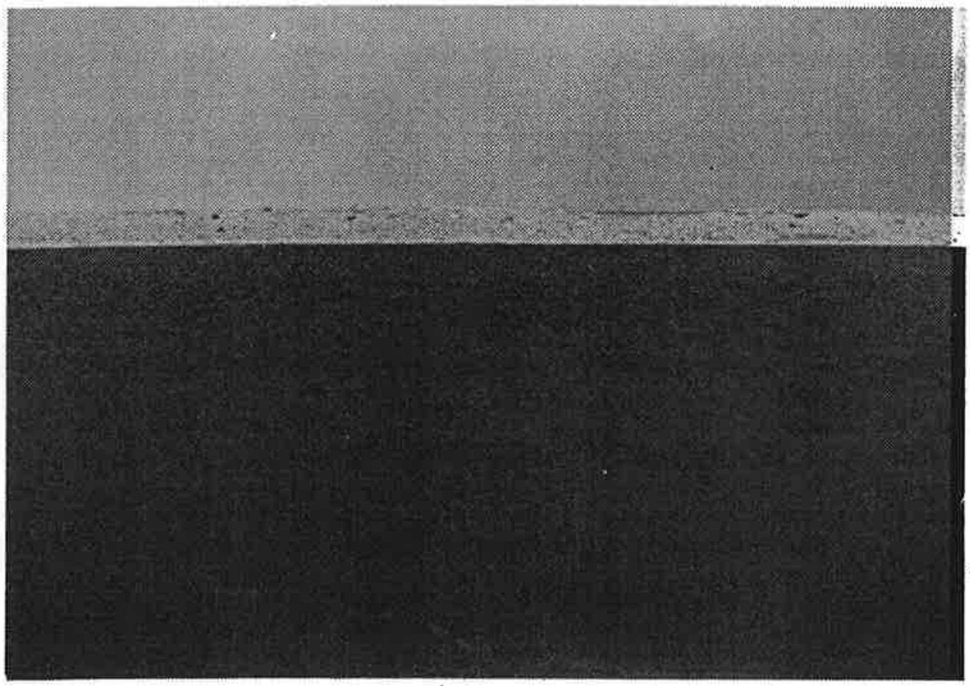


Photograph No.: D-14

Material No. 15

Description: High humidity resistance gypsum board.

Thickness: 12.7 mm

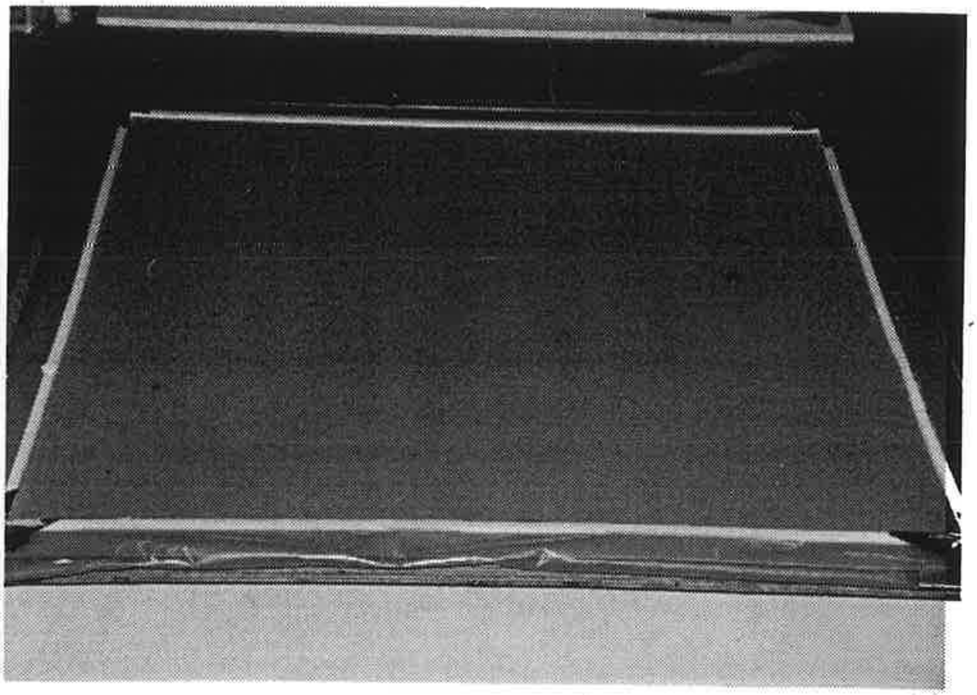


Photograph No.: D-15

Material No. 16

Description: Tempered hardboard.

Thickness: 3.2 mm

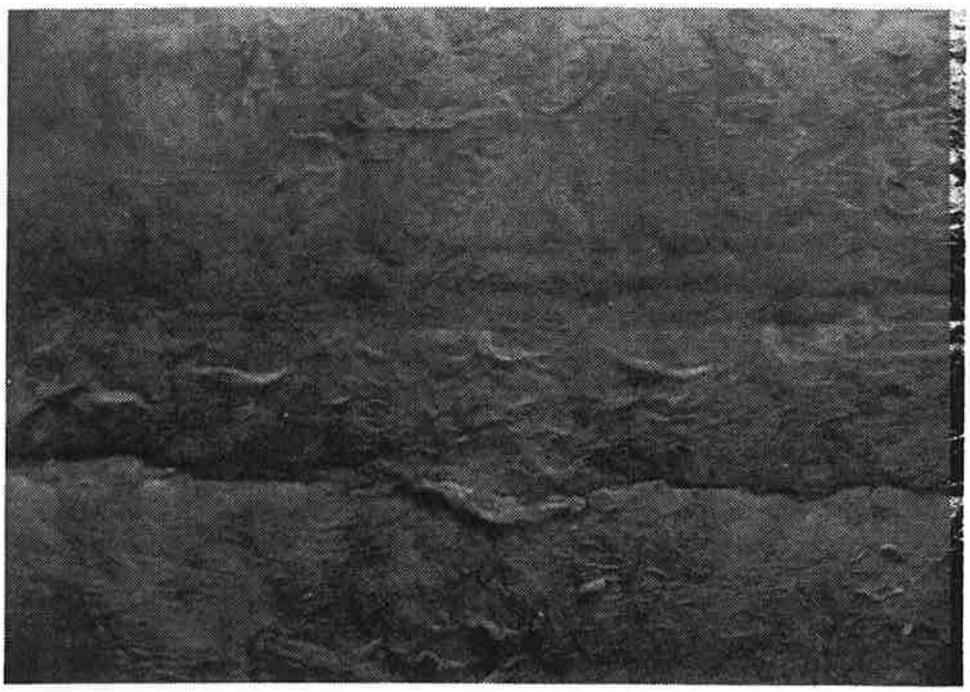


Photograph No.: D-16

Material No. 17

Description: Glass wool insulation.

Thickness: 152 mm

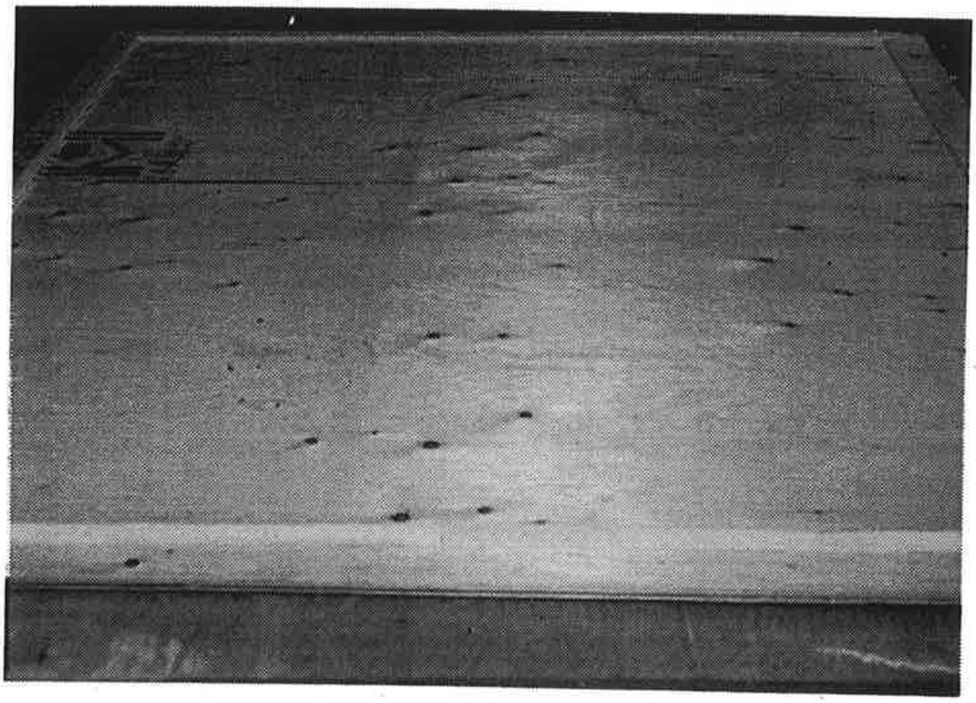


Photograph No.: D-17

Material No. 18

Description: 3 plys plywood sheating.

Thickness: 8 mm

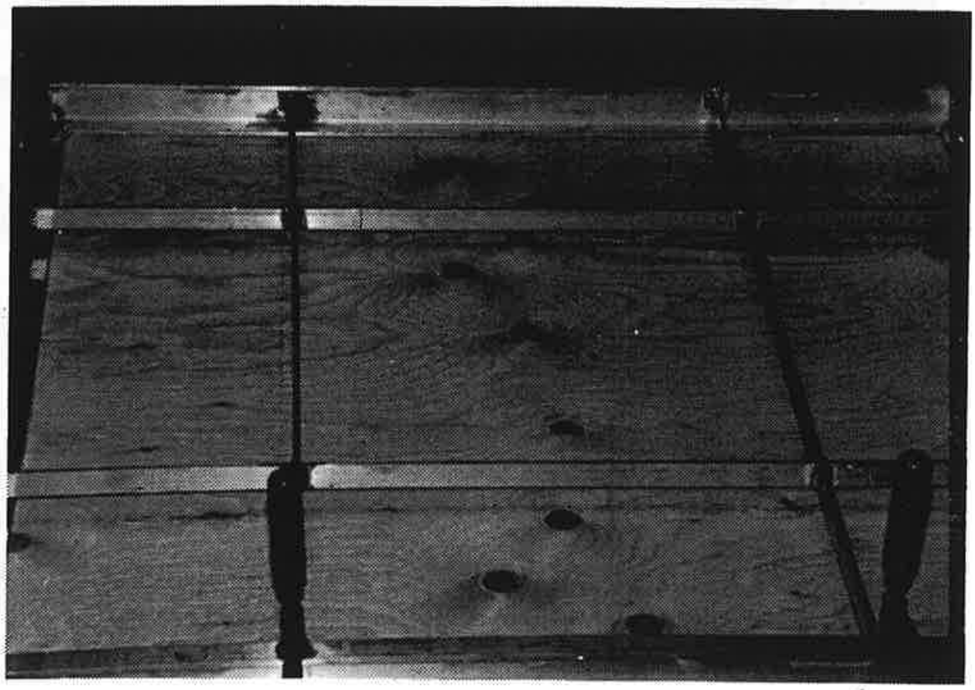


Photograph No.: D-18

Material No. 19

Description: 3 plys plywood sheating.

Thickness: 9.5 mm

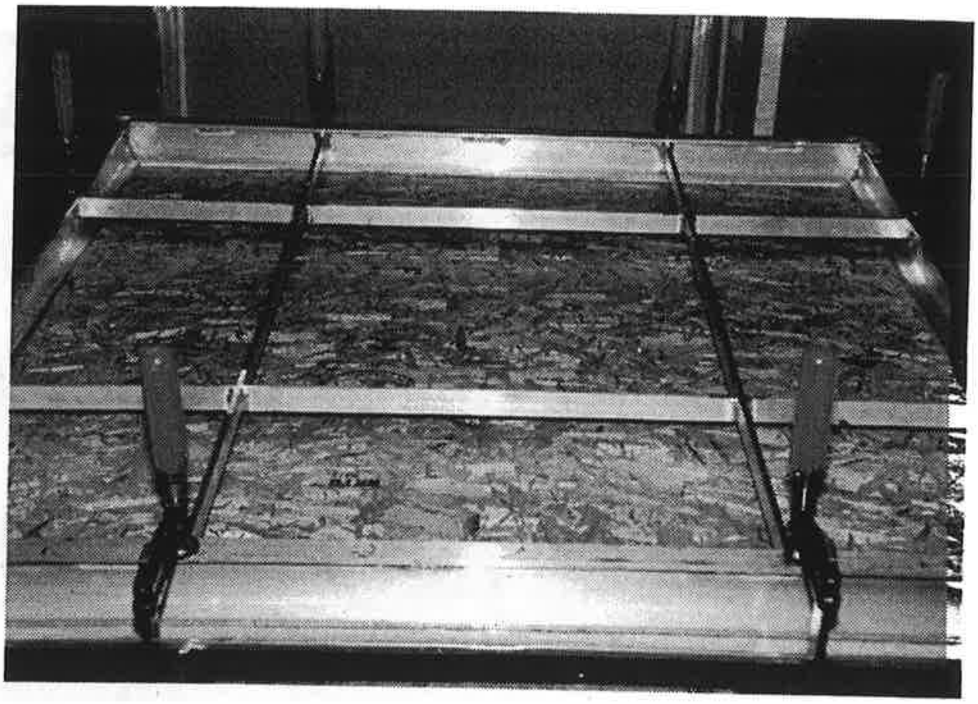


Photograph No.: D-19

<u>Material No. 20</u>

<u>Description:</u> Flake wood board.

<u>Thickness:</u> 11 mm



Photograph No.: D-20

Material No. 21

Description: Flake wood board.

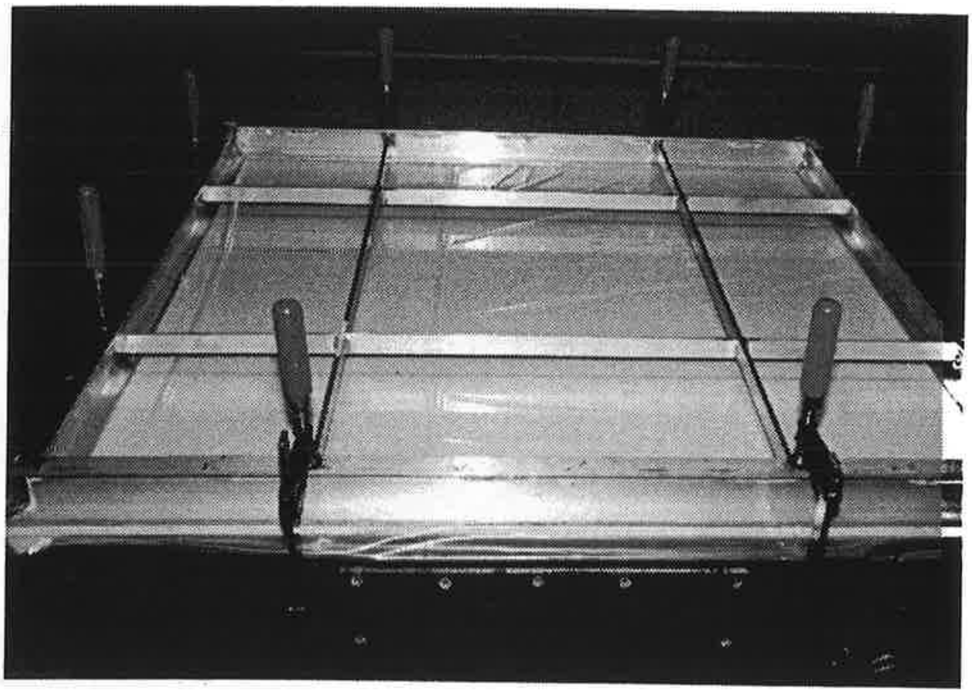
Thickness: 16 mm

Photograph No.: D-21

Material No. 22

Description: Particle board.

Thickness: 12.7 mm

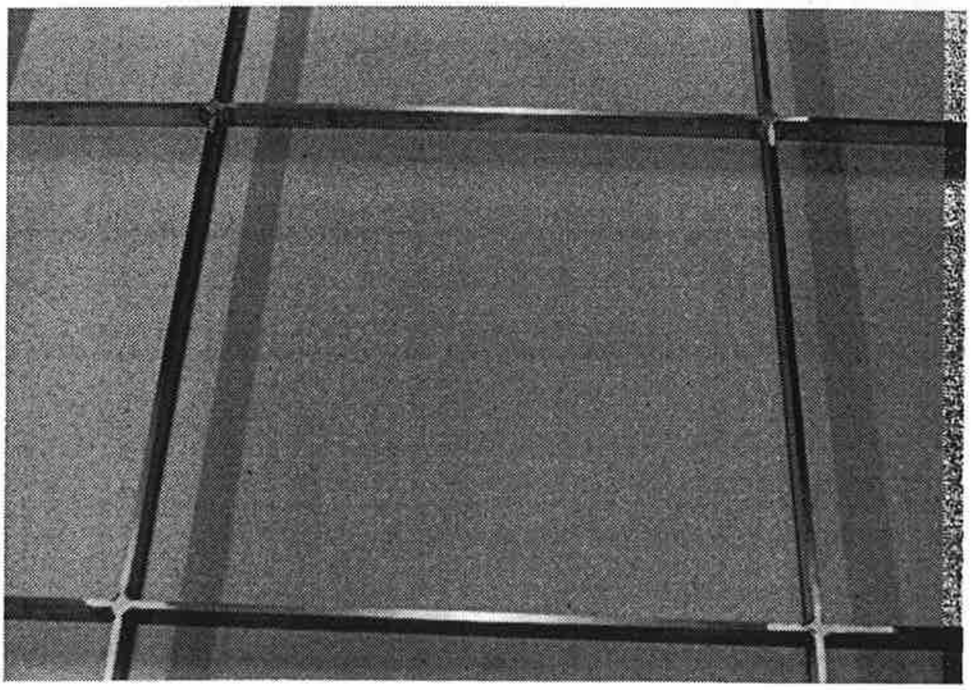


Photograph No.: D-22

Material No. 23

Description: Particle board.

Thickness: 16 mm

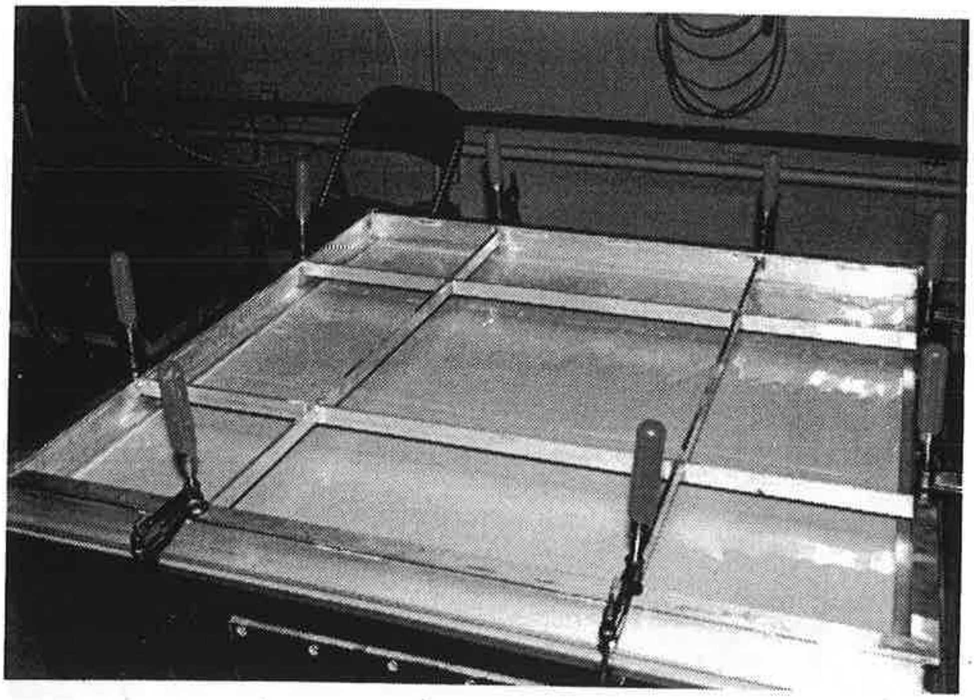


Photograph No.: D-23

Material No. 24

Description: Plain fiberboard.

Thickness: 1·1mm

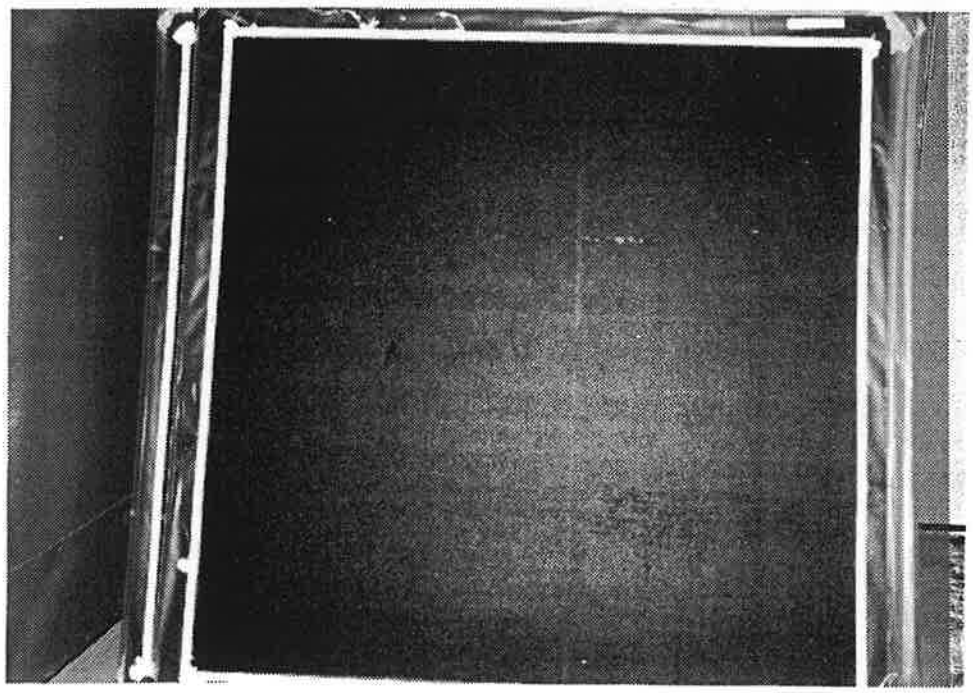


Photograph No.: D-24

Material No. 25

Description: Fiberboard (asphalt coated on both faces).

Thickness: 11 mm

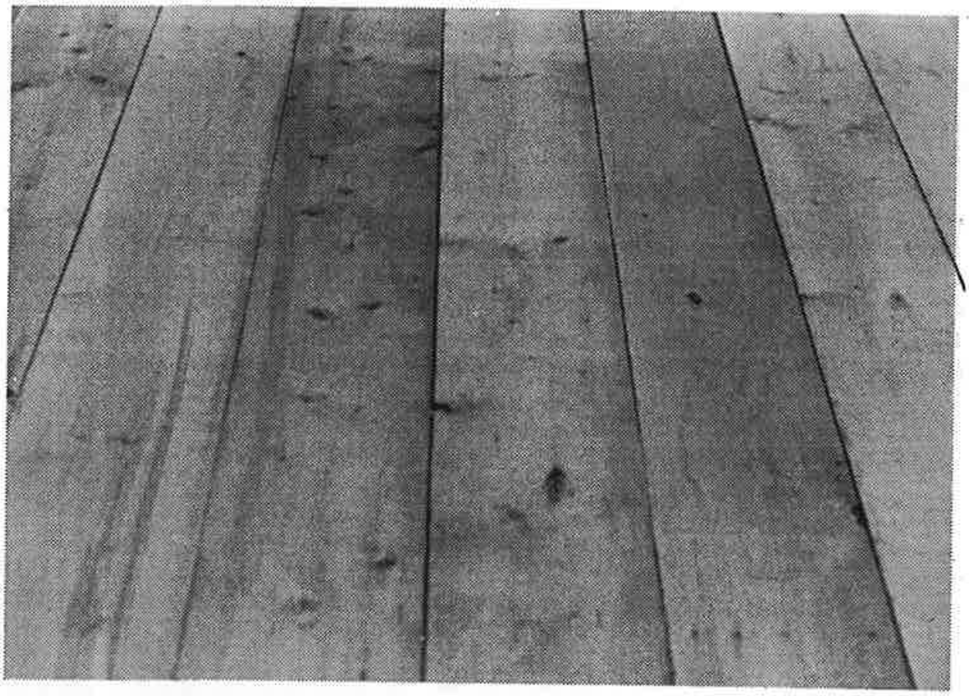


Photograph No.: D-25

Material No. 26

Description: 15 mm thick x 127 mm wide tongue and groove planks.

Number of joints = 8

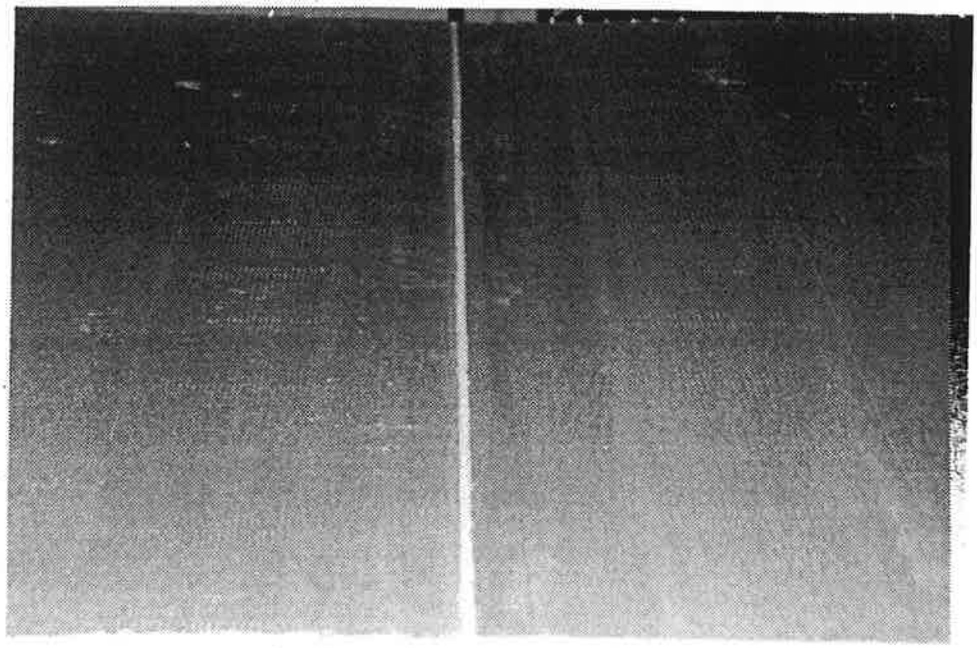


Photograph No.: D-26

Material No. 27

Description: Extruded polystyrene.

Thickness: 38 mm

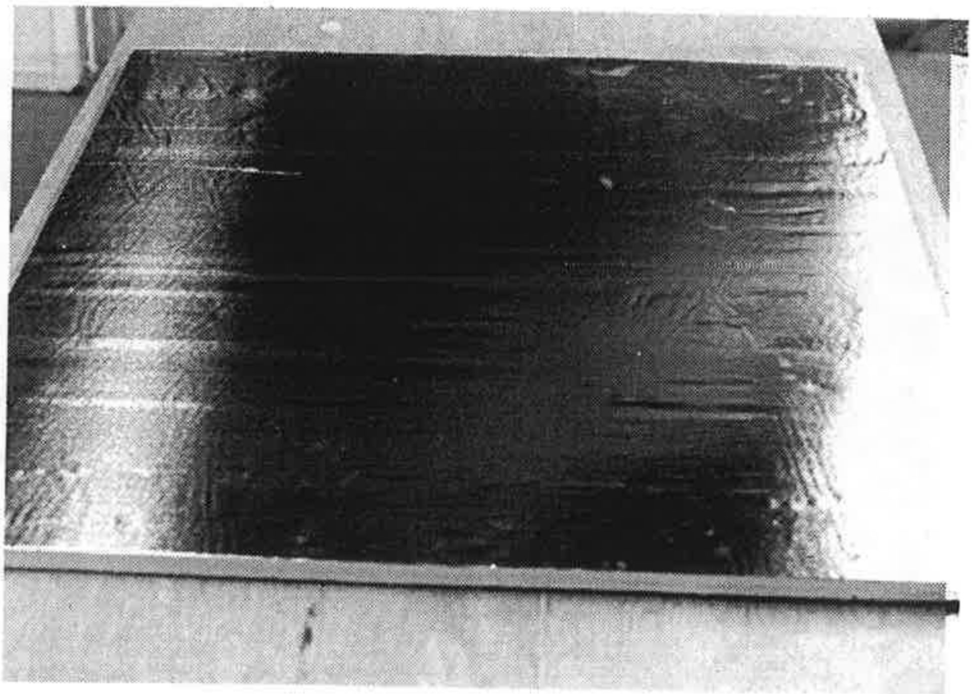


Photograph No.: D-27

Material No. 28

Description: Urethane board faced with aluminum foil on both faces.

Thickness: 25.4 mm

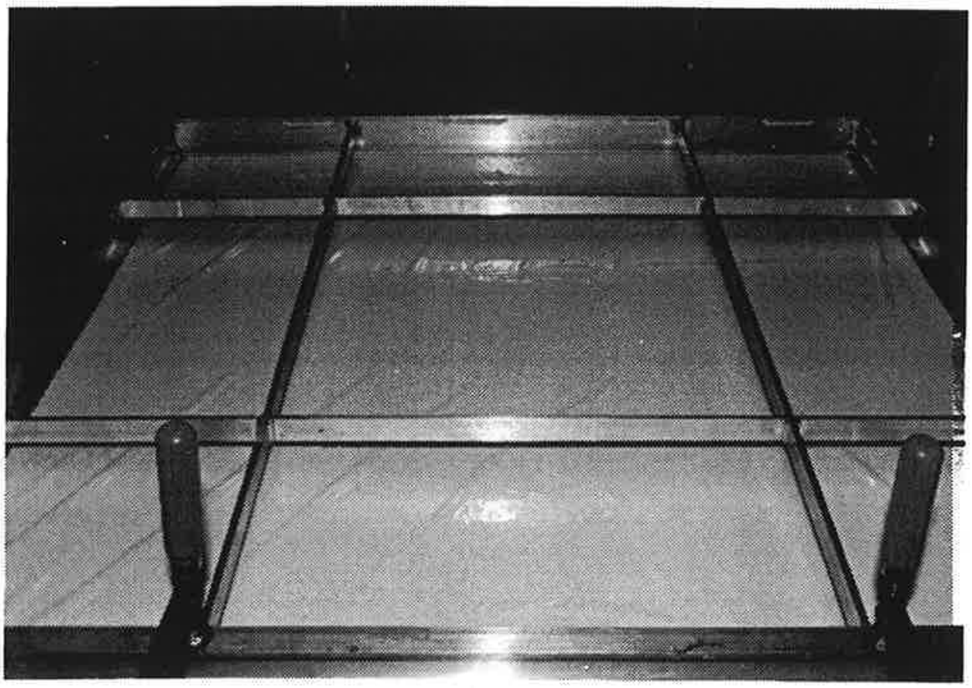


Photograph No.: D-28

Material No. 29

Description: Expanded polystyrene insulation board (type 1).

Thickness: 25.4 mm

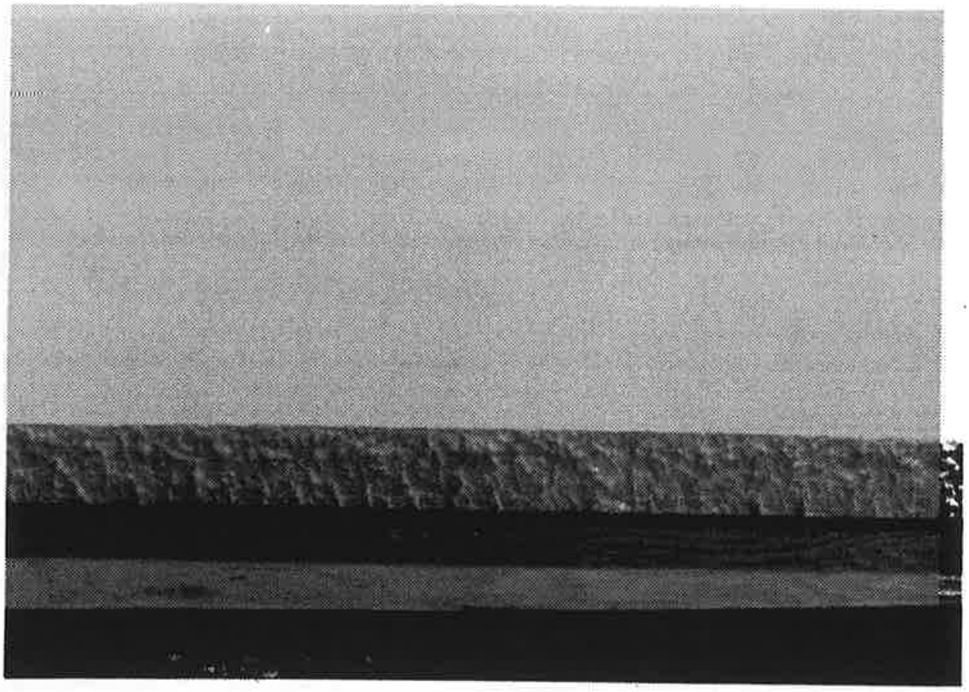


Photograph No.: D-29

Material No. 30

Description: Expanded polystyrene insulating board (type 2).

Thickness: 25.4 mm

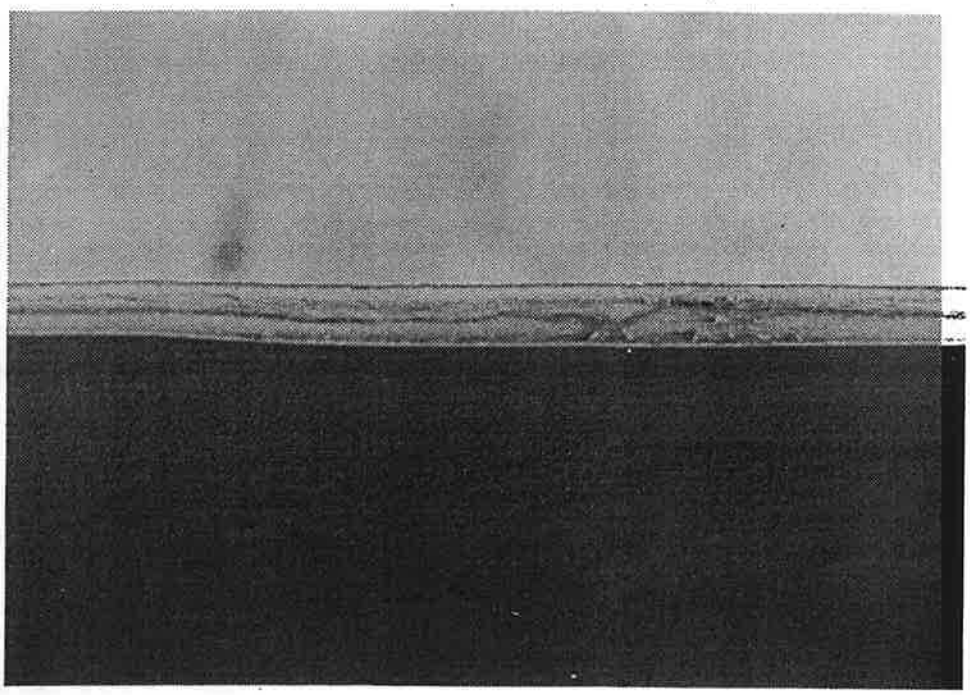


Photograph No.: D-30

Material No. 31

Description: Phenolic insulation board faced with kraft paper having a polyethylene enduction and 10 perforations per cm^2 on both faces.

Thickness: 24 mm

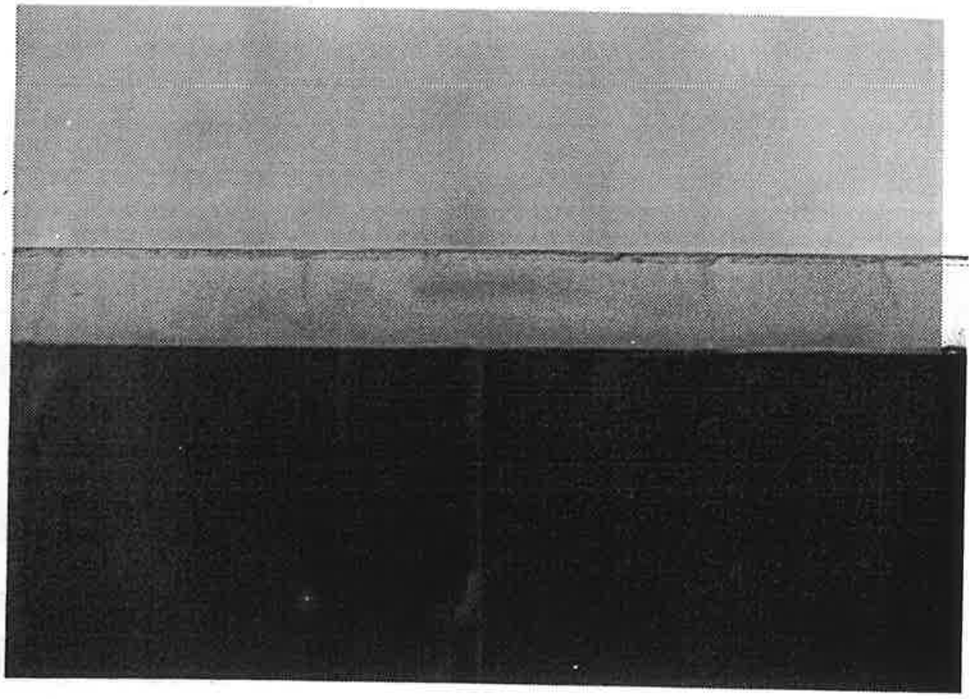


Photograph No.: D-31

Material No. 32

Description: Phenolic insulation board faced with kraft paper having a polyethylene enduction and 10 perforations per cm^2 on both faces.

Thickness: 42 mm

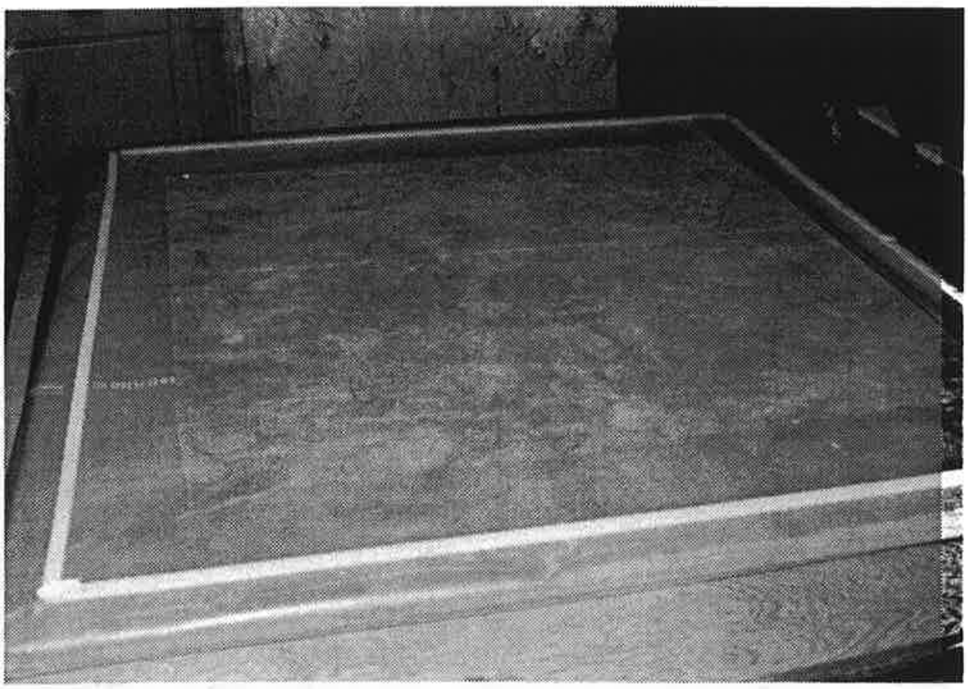


Photograph No.: D-32

Material No. 33

Description: Glass fibre rigid insulation board faced with a spunbonded olefin film on one side.

Thickness: Film : 5 mils
Glass fibre: 25.4 mm



Photograph No.: D-33

Material No. 34

Description: Vermiculite loose fill insulation.

Thickness: 75 mm

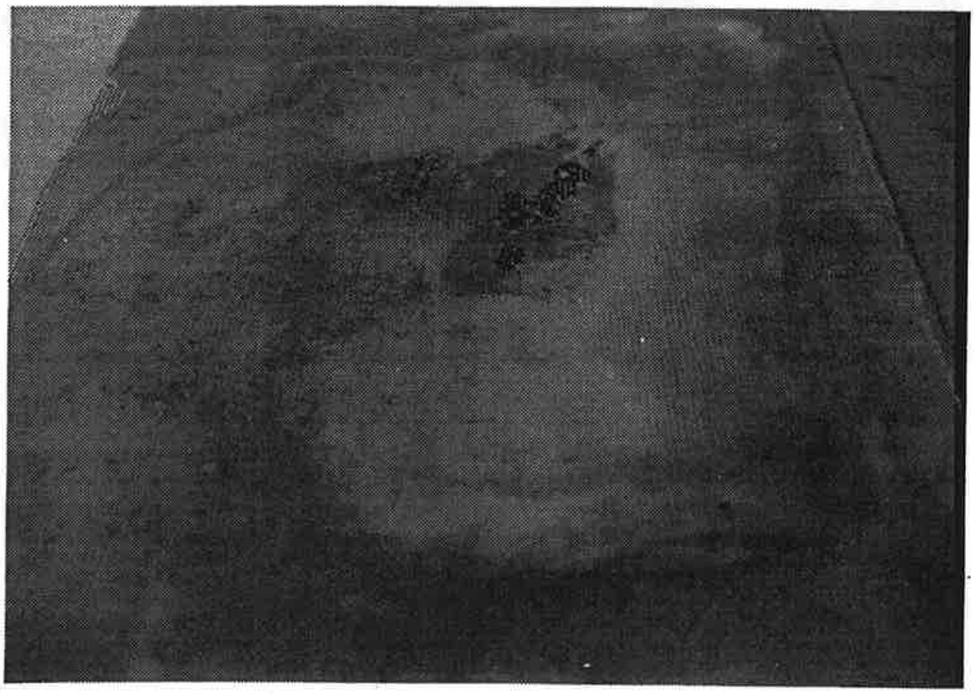
Mass per unit area : 4.5 kg/m^2

Photograph No.: D-34

Material No. 35

Description: Cement board made of sand, portland cement, water, polystyrene particles, polymer resin and admixtures. A fiber glass netting is incorporated on both sides of the board.

Thickness: 12.7 mm

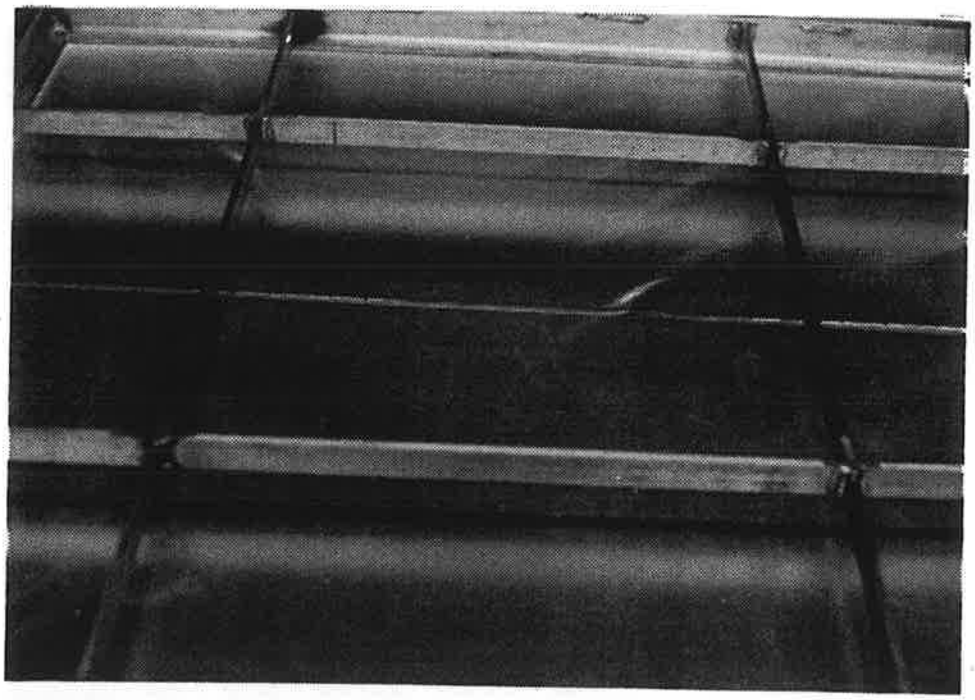


Photograph No.: D-35

Material No. 36

Description: Aluminum foil back gypsum board.

Thickness: 12.7 mm



Photograph No.: D-36

APPENDIX "E"

DETAILED TEST RESULTS

MATERIAL NO.: 1

MATERIAL DESCRIPTION: SPUNBONDED OLEFIN FILM

SPECIMEN	Q_S VERSUS P ($L/S-m^2$)
1 A	$Q_S = 0,01285 \ P^{1.000}$
1 B	$Q_S = 0,01213 \ P^{1.000}$
1 C	$Q_S = 0.01318 \ P^{1.000}$
1 D	$Q_S = 0,01301 \ P^{1.000}$
AVERAGE	$Q_S = 0,01279 \ P^{1.000}$

STATIC PRESSURE DIFFERENTIAL ACROSS THE MATERIAL (Pa)	AIR FLOW RATE (avg) ($L/S-m^2$)	PERMEANCE (avg) (m/Pa-S)	RESISTANCE (avg) (Pa-S/m)
25	0,3198	1.28×10^{-5}	$7.82 \times 10^{+4}$
50	0,6395	1.28×10^{-5}	$7.82 \times 10^{+4}$
75	0,9593	1.28×10^{-5}	$7.82 \times 10^{+4}$
100	1,2790	1.28×10^{-5}	$7.82 \times 10^{+4}$

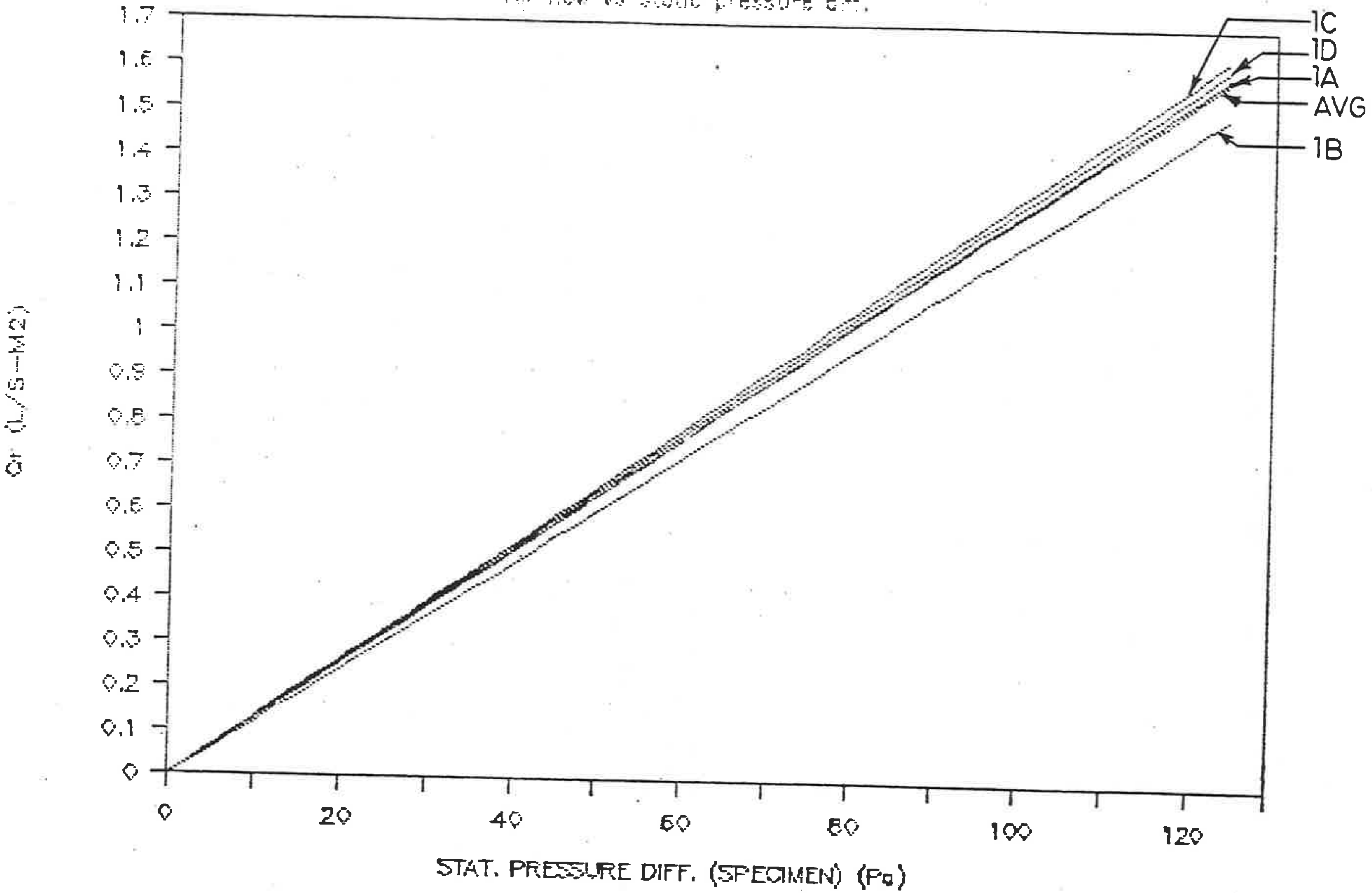
EQUIVALENT LEAKAGE AREA:

ELA = $5,135 \times 10^{-5} \ m^2$

Diam. ELA = 8.08554 mm

SPECIMEN'S CURVES

Air flow vs static pressure diff.



MATERIAL NO.: 2

MATERIAL DESCRIPTION: PERFORATED POLYETHYLENE FILM NO.1

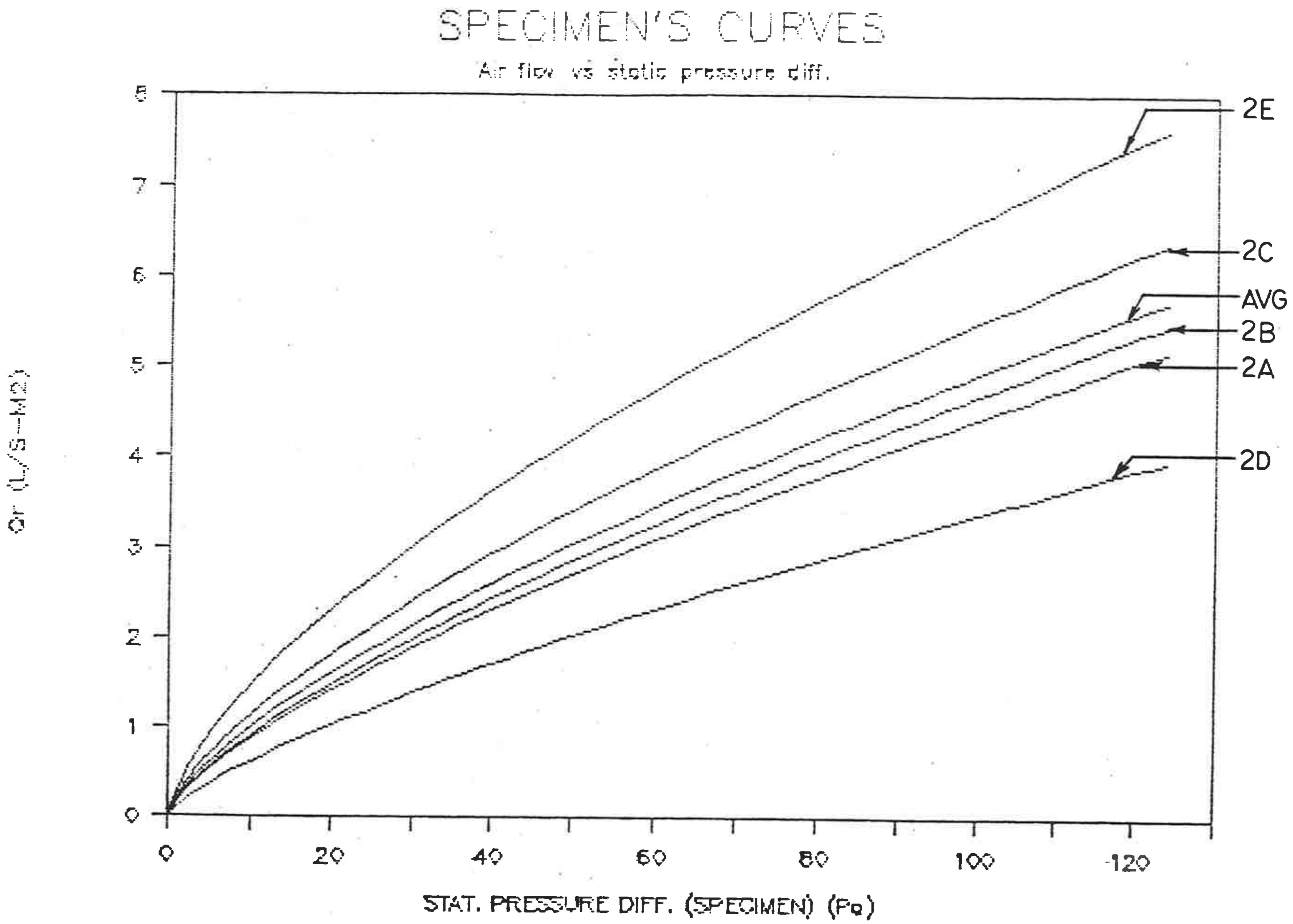
SPECIMEN	Q_S VERSUS P (L/S-m^2)
2 A	$Q_S = 0,16792 \ P^{0.71104}$
2 B	$Q_S = 0,17490 \ P^{0.71384}$
2 C	$Q_S = 0,23373 \ P^{0.68555}$
2 D	$Q_S = 0,11106 \ P^{0.74173}$
2 E	$Q_S = 0,32493 \ P^{0.65471}$
AVERAGE	$Q_S = 0,20120 \ P^{0.69432}$

STATIC PRESSURE DIFFERENTIAL ACROSS THE MATERIAL (Pa)	AIR FLOW RATE (avg) (L/S-m^2)	PERMEANCE (avg) (m/Pa-S)	RESISTANCE (avg) (Pa-S/m)
25	1,8804	7.52×10^{-5}	$1.33 \times 10^{+4}$
50	3,0427	6.09×10^{-5}	$1.64 \times 10^{+4}$
75	4,0320	5.38×10^{-5}	$1.86 \times 10^{+4}$
100	4,9235	4.92×10^{-5}	$2.03 \times 10^{+4}$

EQUIVALENT LEAKAGE AREA:

ELA = 3.996×10^{-4} m^2

Diam. ELA = 22.55525 mm


SPECIMEN'S CURVES
Air flow vs static pressure diff.
Qr (L/S-M2)
STAT. PRESSURE DIFF. (SPECIMEN) (Pa)
0
1
2
3
4
5
6
7
8
0
20
40
60
80
100
120
2E
2C
AVG
2B
2A
2D

MATERIAL NO.: 3

MATERIAL DESCRIPTION: PERFORATED POLYETHYLENE FILM NO.2

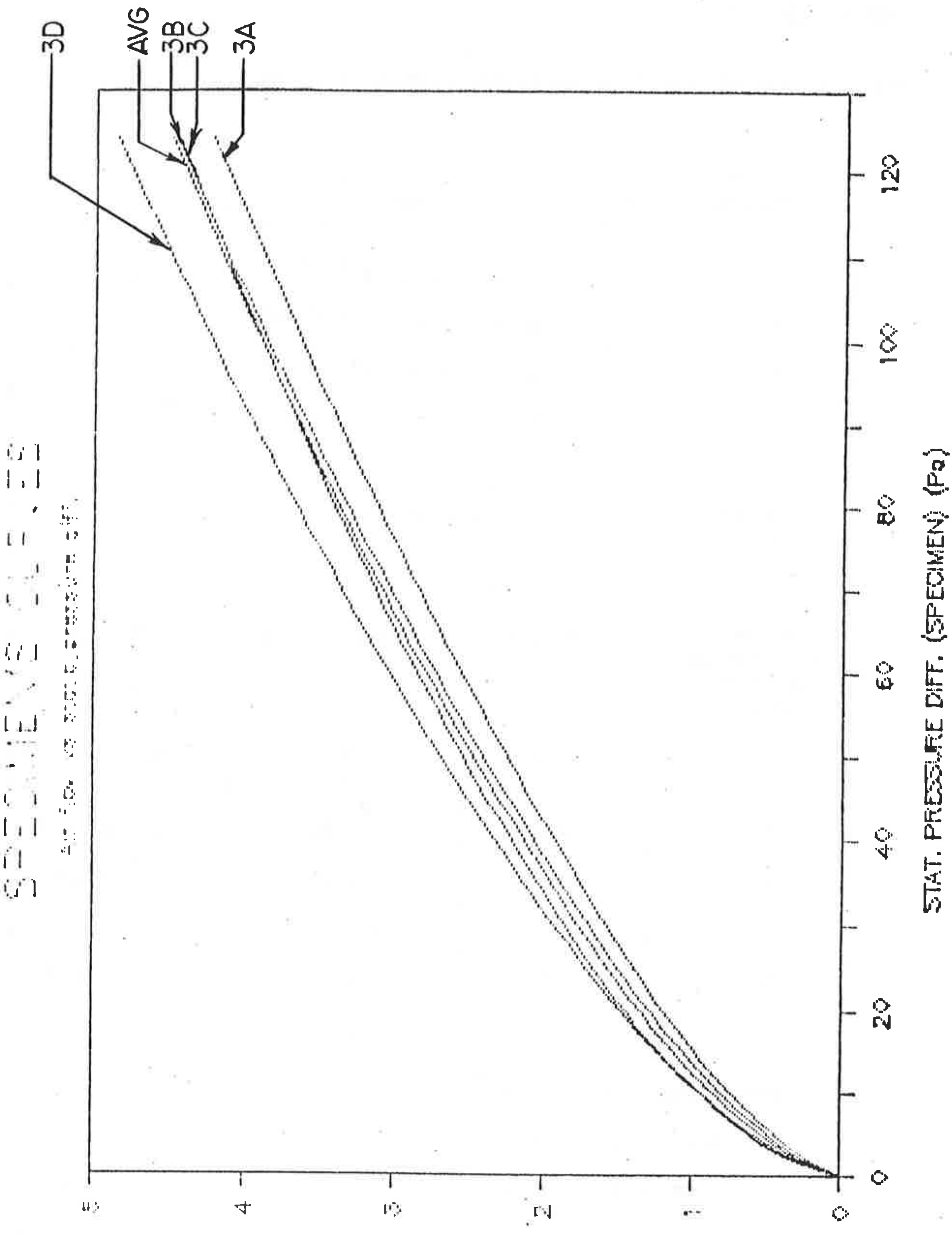
SPECIMEN	Q_S VERSUS P (L/S-m^2)
3 A	$Q_S = 0{,}15006\ P^{0.69206}$
3 B	$Q_S = 0{,}22973\ P^{0.61478}$
3 C	$Q_S = 0{,}16657\ P^{0.68258}$
3 D	$Q_S = 0{,}21033\ P^{0.65164}$
AVERAGE	$Q_S = 0{,}18789\ P^{0.65885}$

STATIC PRESSURE DIFFERENTIAL ACROSS THE MATERIAL (Pa)	AIR FLOW RATE (avg) (L/S-m^2)	PERMEANCE (avg) (m/Pa-S)	RESISTANCE(avg) (Pa-S/m)
25	1,5665	6.27×10^{-5}	$1.60 \times 10^{+4}$
50	2,4733	4.95×10^{-5}	$2.02 \times 10^{+4}$
75	3,2307	4.31×10^{-5}	$2.32 \times 10^{+4}$
100	3,9049	3.90×10^{-5}	$2.56 \times 10^{+4}$

EQUIVALENT LEAKAGE AREA:

$ELA = 3.439 \times 10^{-4}\ m^2$

Diam. ELA = 20.92432 mm


3D
AVG
3B
3C
3A
0
20
40
60
80
100
120
STAT. PRESSURE DIFF. (SPECIMEN) (Pa)
0
4

MATERIAL NO.: 6

MATERIAL DESCRIPTION: REINFORCED NON PERFORATED POLYOLEFIN

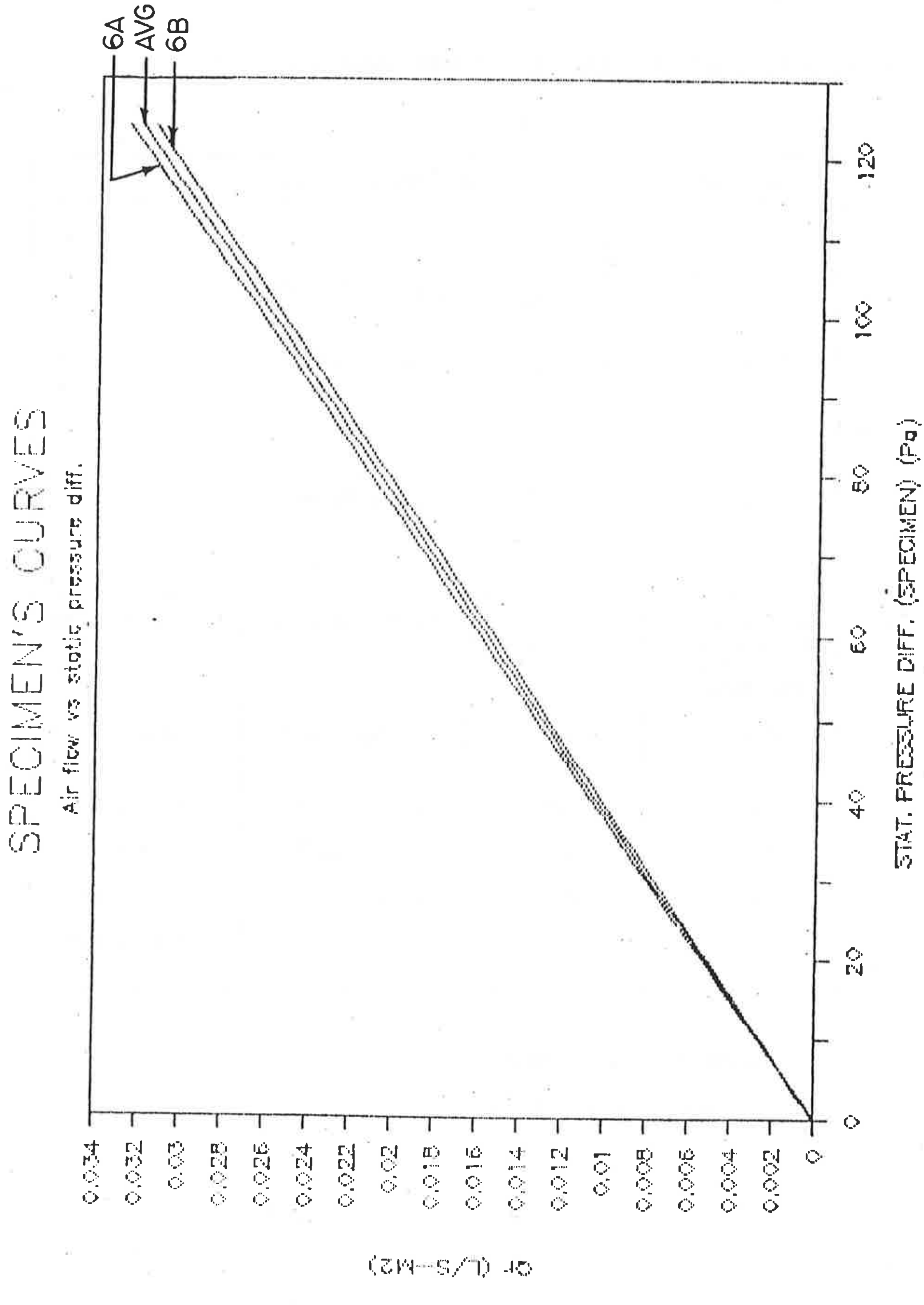
SPECIMEN	Q_S VERSUS P (L/S-m^2)
6 A	$Q_S = 0{,}00028\ P^{0{,}98628}$
6 B	$Q_S = 0{,}00026\ P^{0{,}99169}$
AVERAGE	$Q_S = 0{,}00027\ P^{0{,}98893}$

STATIC PRESSURE DIFFERENTIAL ACROSS THE MATERIAL (Pa)	AIR FLOW RATE (avg) (L/S-m^2)	PERMEANCE (avg) (m/Pa-S)	RESISTANCE (avg) (Pa-S/m)
25	0,0066	2.63×10^{-7}	$3.80 \times 10^{+6}$
50	0,0131	2.61×10^{-7}	$3.83 \times 10^{+6}$
75	0,0195	2.60×10^{-7}	$3.84 \times 10^{+6}$
100	0,0259	2.59×10^{-7}	$3.86 \times 10^{+6}$

EQUIVALENT LEAKAGE AREA:

ELA = $1.068 \times 10^{-6}\ m^2$

Diam. ELA = 1.16630 mm


SPECIMEN'S CURVES
Air flow vs static pressure diff.
6A
AVG
6B
Qr (L/S-M2)
0
0.002
0.004
0.006
0.008
0.01
0.012
0.014
0.016
0.018
0.02
0.022
0.024
0.026
0.028
0.03
0.032
0.034
0
20
40
60
80
100
120
STAT. PRESSURE DIFF. (SPECIMEN) (Pa)

MATERIAL NO.: 7

MATERIAL DESCRIPTION: 38 mm CELLULOSE INSULATION

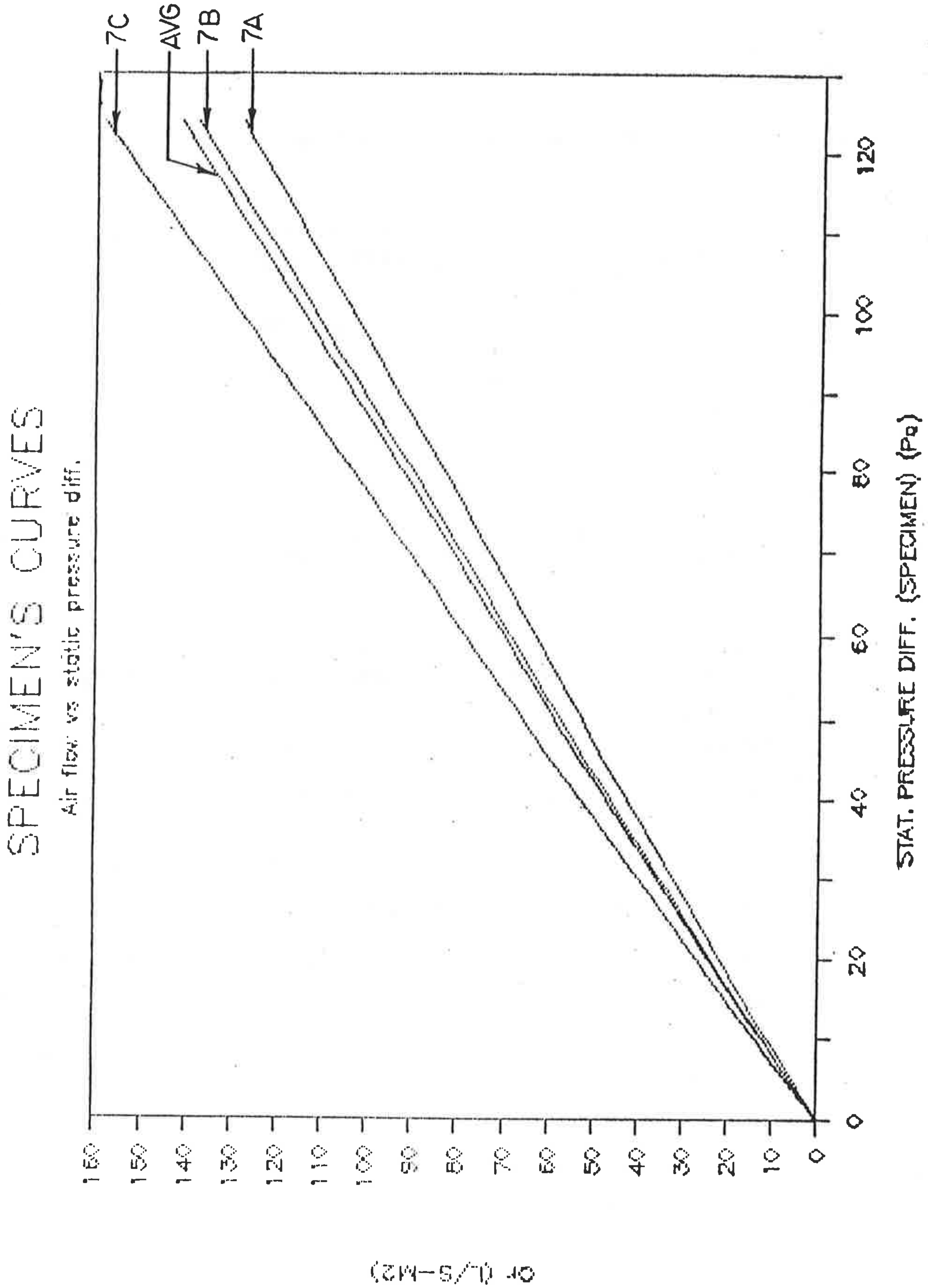
SPECIMEN	Q_S VERSUS P (L/S-m^2)
7 A	$Q_S = 1{,}15655 \; P^{0{,}97656}$
7 B	$Q_S = 1{,}32003 \; P^{0{,}96454}$
7 C	$Q_S = 1{,}48923 \; P^{0{,}96851}$
AVERAGE	$Q_S = 1{,}32171 \; P^{0{,}96963}$

STATIC PRESSURE DIFFERENTIAL ACROSS THE MATERIAL (Pa)	AIR FLOW RATE (avg) (L/S-m^2)	PERMEANCE (avg) (m/Pa-S)	RESISTANCE(avg) (Pa-S/m)
25	29,9652	1.20×10^{-3}	$8.34 \times 10^{+2}$
50	58,6820	1.17×10^{-3}	$8.52 \times 10^{+2}$
75	86,9457	1.16×10^{-3}	$8.63 \times 10^{+2}$
100	114,9191	1.15×10^{-3}	$8.70 \times 10^{+2}$

EQUIVALENT LEAKAGE AREA:

ELA = 4.948×10^{-3} m^2

Diam. ELA = 79.36955 mm


SPECIMEN'S CURVES
Air flow vs static pressure diff.
7C
AVG
7B
7A
STAT. PRESSURE DIFF. (SPECIMEN) (Pa)
Qr (L/S-M2)
0
20
40
60
80
100
120
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160

MATERIAL NO.: 9

MATERIAL DESCRIPTION: 15 lb NON-PERFORATED ASPHALT FELT

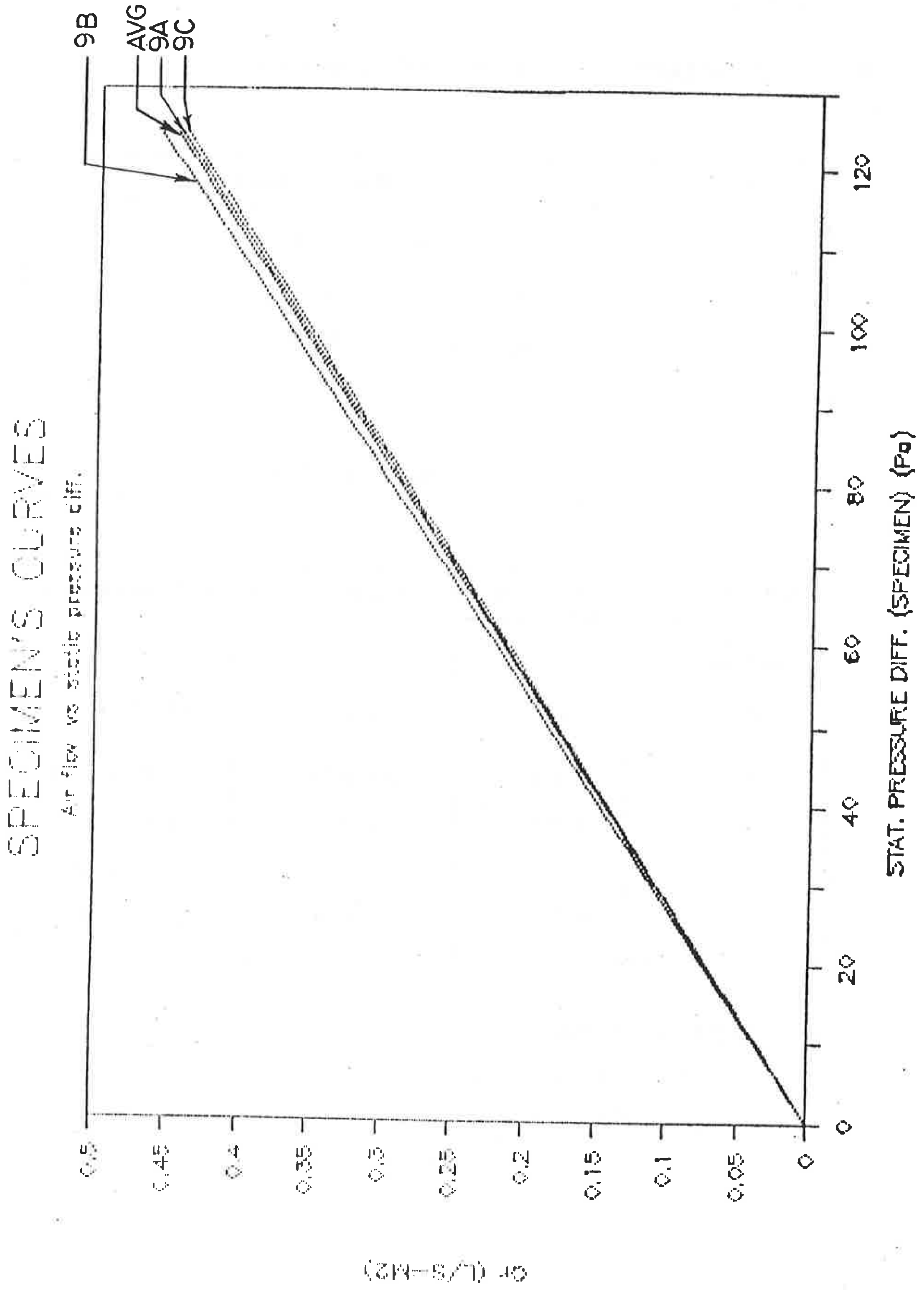
SPECIMEN	Q_S VERSUS P ($L/S\text{-}m^2$)
9 A	$Q_S = 0,00357 \; P^{1,000}$
9 B	$Q_S = 0,00370 \; P^{1,000}$
9 C	$Q_S = 0,00355 \; P^{1,000}$
AVERAGE	$Q_S = 0,00361 \; P^{1,000}$

STATIC PRESSURE DIFFERENTIAL ACROSS THE MATERIAL (Pa)	AIR FLOW RATE (avg) ($L/S\text{-}m^2$)	PERMEANCE (avg) (m/Pa-S)	RESISTANCE (avg) (Pa-S/m)
25	0,0902	3.61×10^{-6}	$2.77 \times 10^{+5}$
50	0,1804	3.61×10^{-6}	$2.77 \times 10^{+5}$
75	0,2706	3.61×10^{-6}	$2.77 \times 10^{+5}$
100	0,3607	3.61×10^{-6}	$2.77 \times 10^{+5}$

EQUIVALENT LEAKAGE AREA:

ELA = 1.448×10^{-5} m^2

Diam. ELA = 4.29406 mm


SPECIMEN'S CURVES
Air flow vs static pressure diff.
9B
AVG
9A
9C
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
0
20
40
60
80
100
120
STAT. PRESSURE DIFF. (SPECIMEN) (Pa)

MATERIAL NO.: 10

MATERIAL DESCRIPTION: 15 lb ASPHAT FELT WITH AIR VENTS

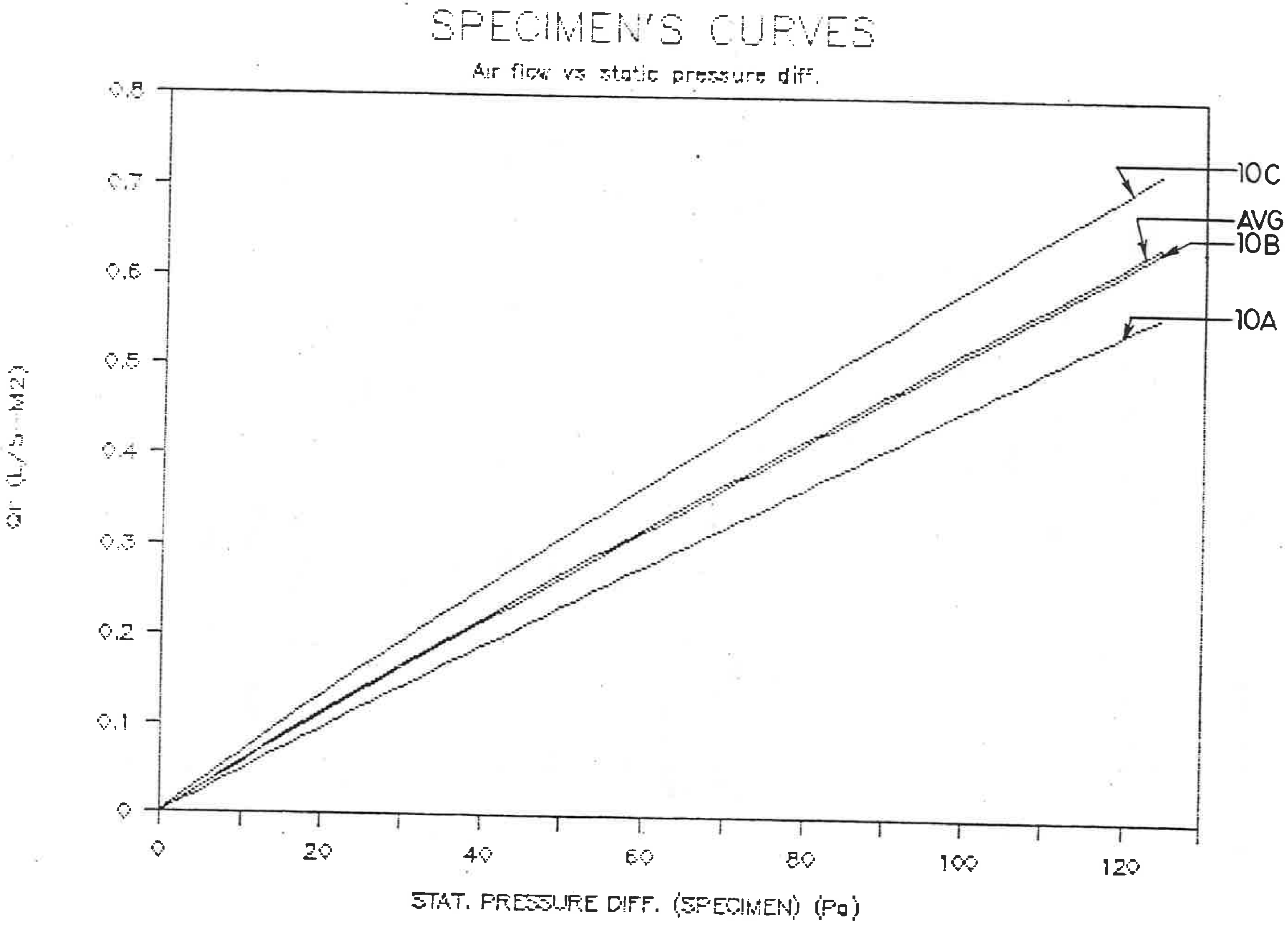
SPECIMEN	Q_S VERSUS P ($L/S-m^2$)
10 A	$Q_S = 0,00532 \quad P^{0,96644}$
10 B	$Q_S = 0,00631 \quad P^{0,92242}$
10 C	$Q_S = 0,00830 \quad P^{0,92579}$
AVERAGE	$Q_S = 0,06629 \quad P^{0,94740}$

STATIC PRESSURE DIFFERENTIAL ACROSS THE MATERIAL (Pa)	AIR FLOW RATE (avg) ($L/S-m^2$)	PERMEANCE (avg) (m/Pa-S)	RESISTANCE (avg) (Pa-S/m)
25	0,1399	5.60×10^{-6}	$1.79 \times 10^{+5}$
50	0,2698	5.40×10^{-6}	$1.85 \times 10^{+5}$
75	0,3962	5.28×10^{-6}	$1.89 \times 10^{+5}$
100	0,5204	5.20×10^{-6}	$1.92 \times 10^{+5}$

EQUIVALENT LEAKAGE AREA:

$ELA = 2.358 \times 10^{-5}\ m^2$

Diam. ELA = 5.47927 mm


SPECIMEN'S CURVES
Air flow vs static pressure diff.
Qr (L/S-M2)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0
20
40
60
80
100
120
STAT. PRESSURE DIFF. (SPECIMEN) (Pa)
10C
AVG
10B
10A

MATERIAL NO.: 11

MATERIAL DESCRIPTION: 30 lb ROOFING FELT

SPECIMEN	Q_S VERSUS P (L/S-m^2)
11 A	$Q_S = 0{,}00248\ P^{0{,}99975}$
11 B	$Q_S = 0{,}00237\ P^{1{,}000}$
11 C	$Q_S = 0{,}00262\ P^{0{,}99051}$
11 D	$Q_S = 0{,}00267\ P^{0{,}99588}$
AVERAGE	$Q_S = 0{,}00254\ P^{0{,}99646}$

STATIC PRESSURE DIFFERENTIAL ACROSS THE MATERIAL (Pa)	AIR FLOW RATE (avg) (L/S-m^2)	PERMEANCE (avg) (m/Pa-S)	RESISTANCE(avg) (Pa-S/m)
25	0,0627	2.51×10^{-6}	$3.99 \times 10^{+5}$
50	0,1250	2.50×10^{-6}	$4.00 \times 10^{+5}$
75	0,1873	2.50×10^{-6}	$4.01 \times 10^{+5}$
100	0,2494	2.49×10^{-6}	$4.01 \times 10^{+5}$

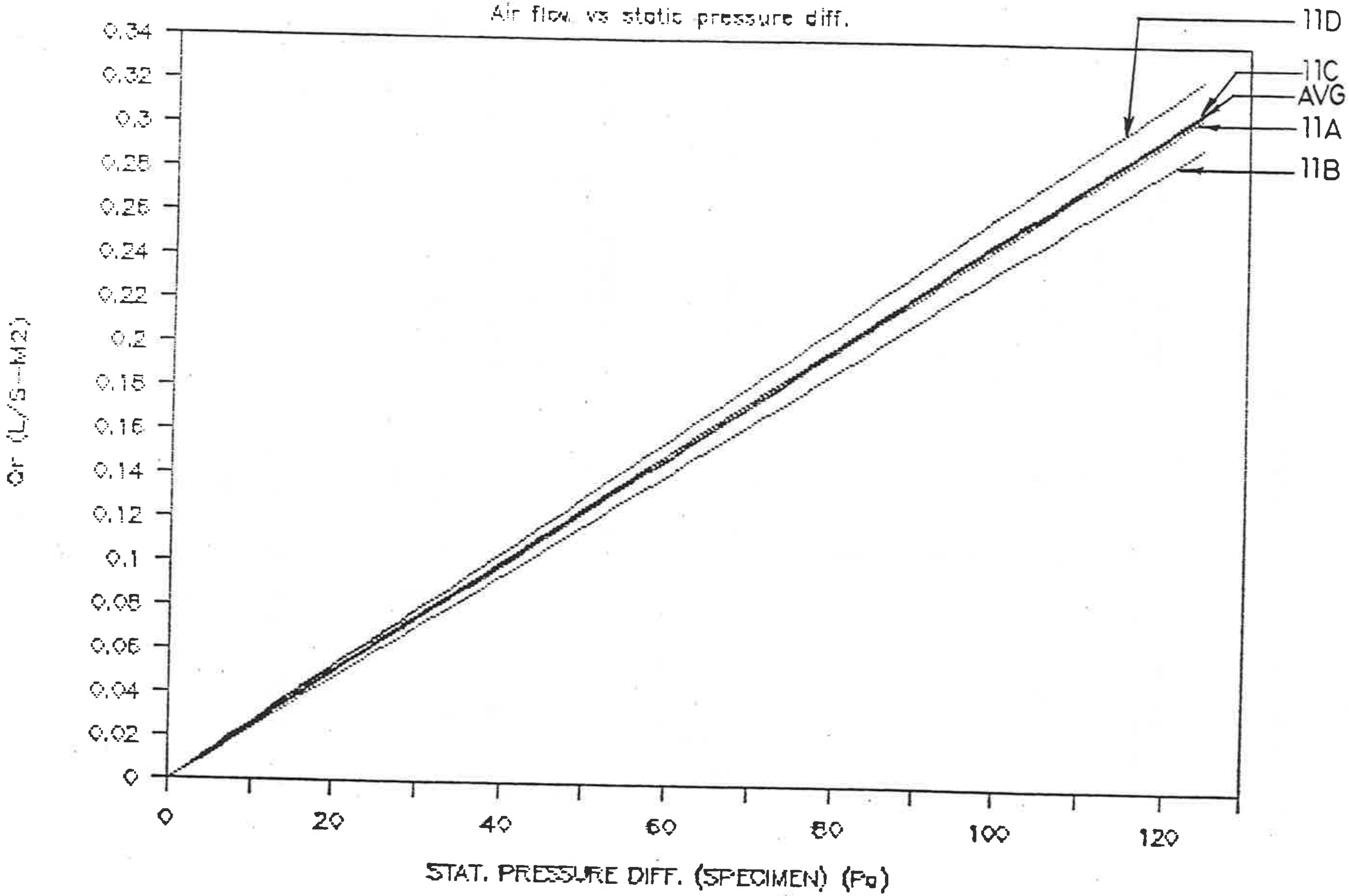
EQUIVALENT LEAKAGE AREA:

ELA = 1.010×10^{-5} m^2

Diam. ELA = 3.58516 mm

SPECIMEN'S CURVES

Air flow vs static pressure diff.



MATERIAL NO.: 14

MATERIAL DESCRIPTION: 12.7 mm GYPSUM BOARD

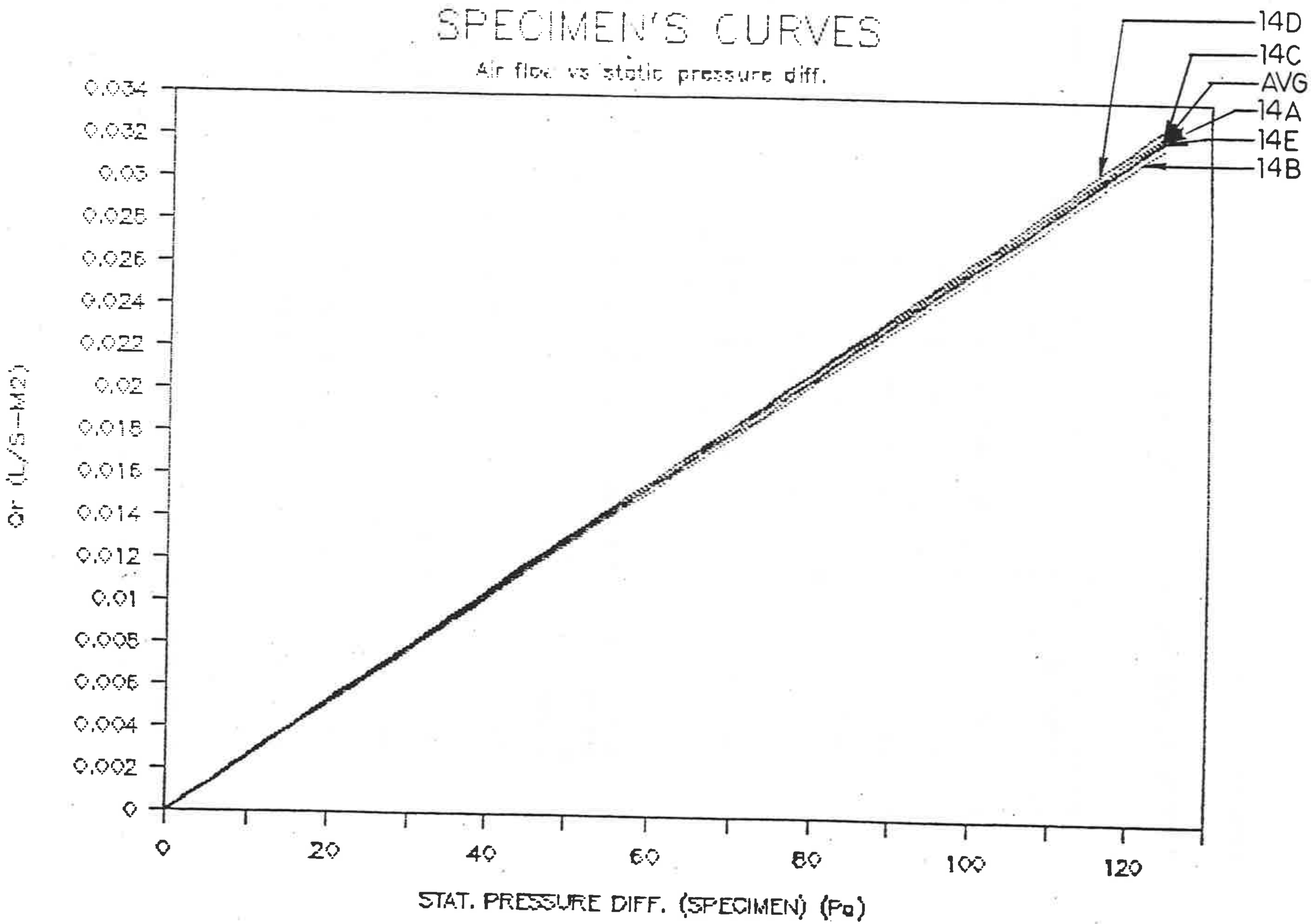
SPECIMEN	Q_S VERSUS P (L/S-m^2)
14 A	$Q_S = 0,00027 \ P^{0,98893}$
14 B	$Q_S = 0,00026 \ P^{1,000}$
14 C	$Q_S = 0,00028 \ P^{0,98846}$
14 D	$Q_S = 0,00027 \ P^{0,99886}$
14 E	$Q_S = 0,00026 \ P^{1,000}$
AVERAGE	$Q_S = 0,00027 \ P^{0,99521}$

STATIC PRESSURE DIFFERENTIAL ACROSS THE MATERIAL (Pa)	AIR FLOW RATE (avg) (L/S-m^2)	PERMEANCE (avg) (m/Pa-S)	RESISTANCE (avg) (Pa-S/m)
25	0,0066	2.63×10^{-7}	$3.81 \times 10^{+6}$
50	0,0131	2.62×10^{-7}	$3.82 \times 10^{+6}$
75	0,0196	2.61×10^{-7}	$3.83 \times 10^{+6}$
100	0,0261	2.61×10^{-7}	$3.83 \times 10^{+6}$

EQUIVALENT LEAKAGE AREA:

ELA = 1.059×10^{-6} m^2

Diam. ELA = 1.16095 mm


SPECIMEN'S CURVES
Air flow vs static pressure diff.
14D
14C
AVG
14A
14E
14B
Qr (L/S-M2)
0.034
0.032
0.03
0.028
0.026
0.024
0.022
0.02
0.018
0.016
0.014
0.012
0.01
0.008
0.006
0.004
0.002
0
20
40
60
80
100
120
STAT. PRESSURE DIFF. (SPECIMEN) (Pa)

MATERIAL NO.: 15

MATERIAL DESCRIPTION: 12.7 mm GYPSUM BOARD M/R

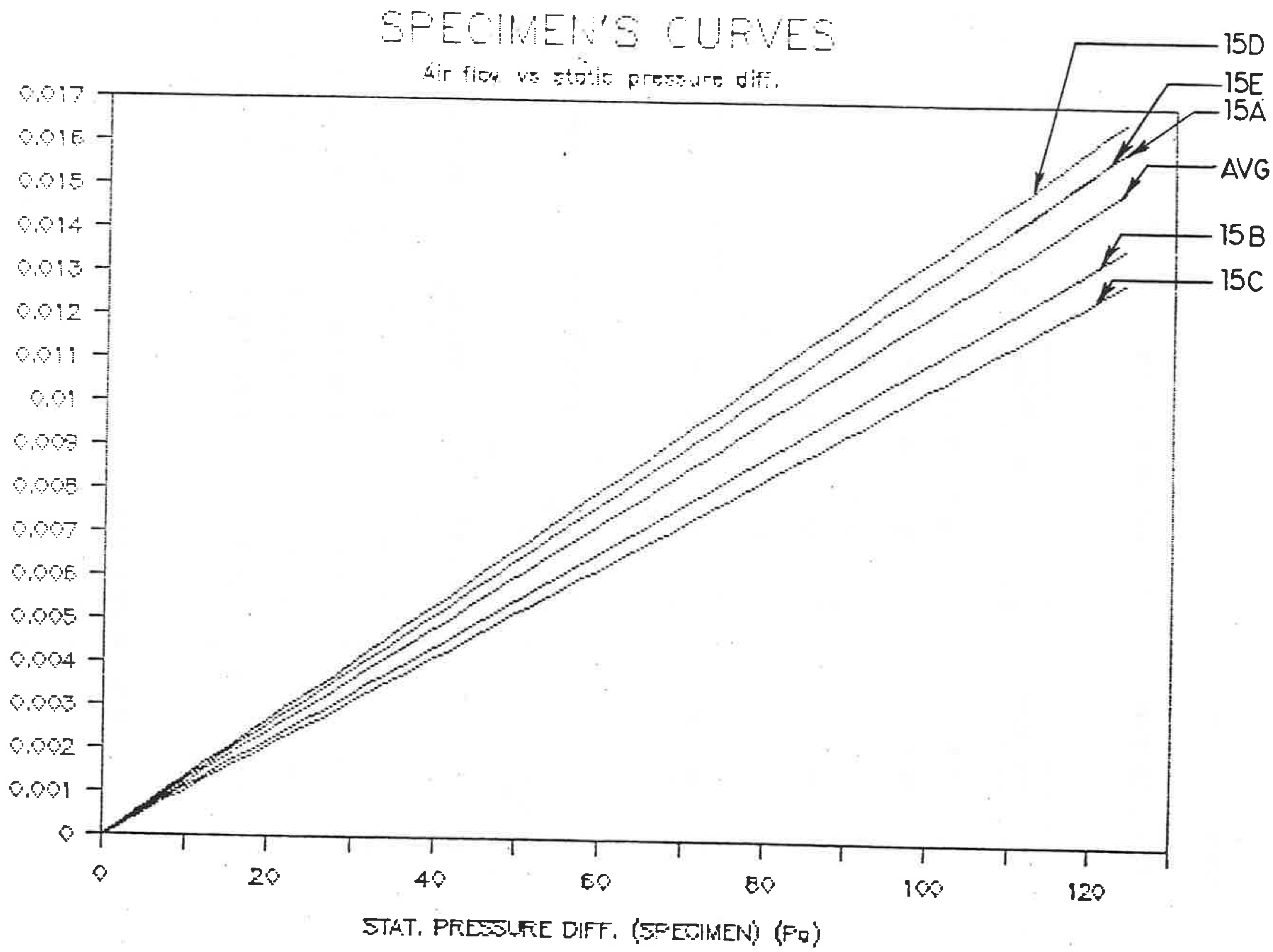
SPECIMEN	Q_S VERSUS P (L/S-m^2)
15 A	$Q_S = 0{,}00013 \; P^{1{,}000}$
15 B	$Q_S = 0{,}00011 \; P^{1{,}000}$
15 C	$Q_S = 0{,}00010 \; P^{1{,}000}$
15 D	$Q_S = 0{,}00013 \; P^{1{,}000}$
15 E	$Q_S = 0{,}00013 \; P^{1{,}000}$
AVERAGE	$Q_S = 0{,}00012 \; P^{1{,}000}$

STATIC PRESSURE DIFFERENTIAL ACROSS THE MATERIAL (Pa)	AIR FLOW RATE (avg) (L/S-m^2)	PERMEANCE (avg) (m/Pa-S)	RESISTANCE(avg) (Pa-S/m)
25	0,0030	1.22×10^{-7}	$8.23 \times 10^{+6}$
50	0,0061	1.22×10^{-7}	$8.23 \times 10^{+6}$
75	0,0091	1.22×10^{-7}	$8.23 \times 10^{+6}$
100	0,0122	1.22×10^{-7}	$8.23 \times 10^{+6}$

EQUIVALENT LEAKAGE AREA:

ELA = 4.879×10^{-7} m^2

Diam. ELA = 0.78818 mm


SPECIMEN'S CURVES
Air flow vs static pressure diff.
15D
15E
15A
AVG
15B
15C
Qr (L/S-M2)
0.017
0.016
0.015
0.014
0.013
0.012
0.011
0.01
0.009
0.008
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0
0
20
40
60
80
100
120
STAT. PRESSURE DIFF. (SPECIMEN) (Pa)

MATERIAL NO.: 16

MATERIAL DESCRIPTION: 3 mm TEMPERED HARDBOARD

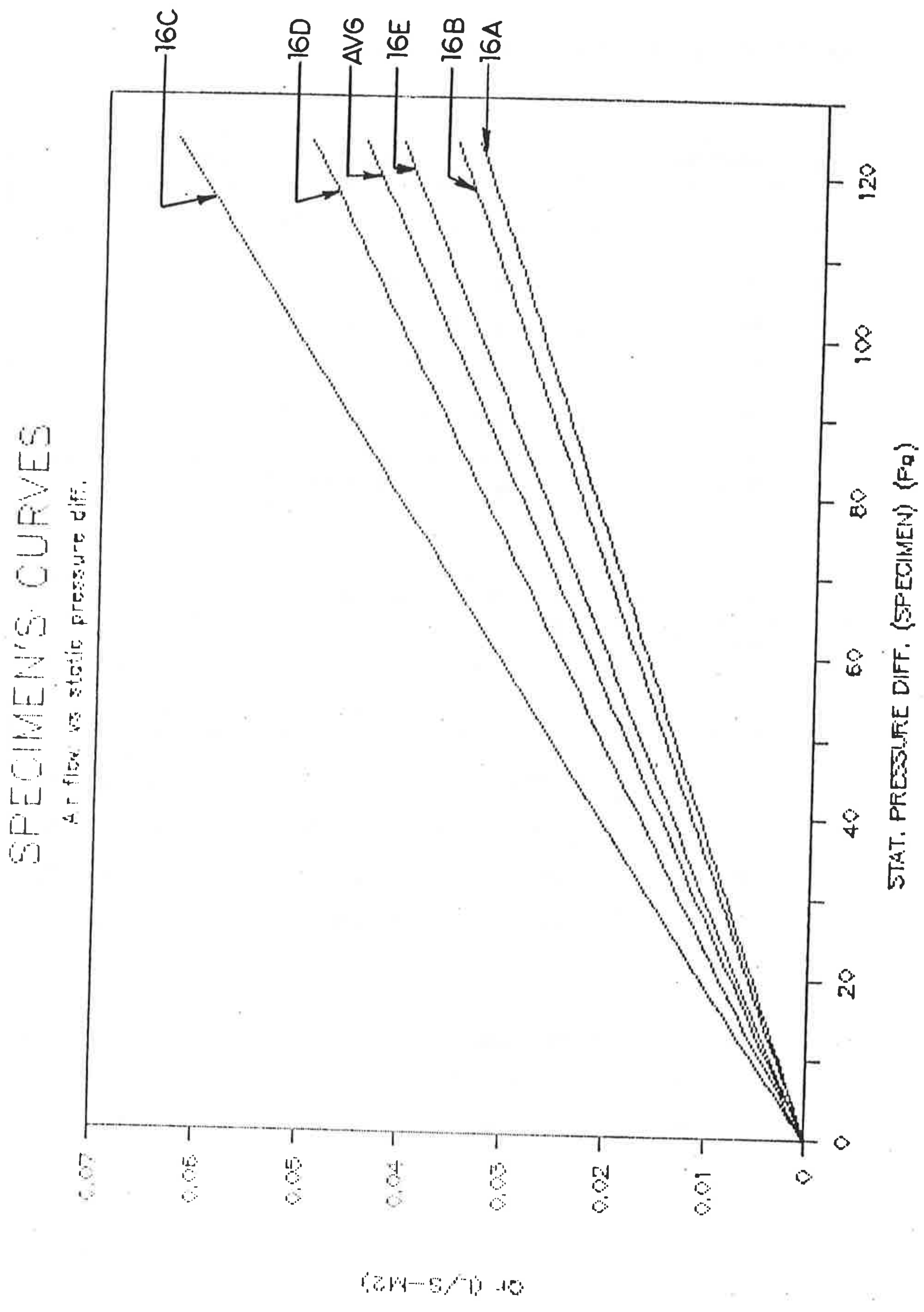
SPECIMEN	Q_S VERSUS P (L/S-m^2)
16 A	$Q_S = 0{,}00027 \; P^{1{,}000}$
16 B	$Q_S = 0{,}00030 \; P^{0{,}99547}$
16 C	$Q_S = 0{,}00057 \; P^{0{,}97595}$
16 D	$Q_S = 0{,}00049 \; P^{0{,}96130}$
16 E	$Q_S = 0{,}00037 \; P^{0{,}97689}$
AVERAGE	$Q_S = 0{,}00040 \; P^{0{,}97945}$

STATIC PRESSURE DIFFERENTIAL ACROSS THE MATERIAL (Pa)	AIR FLOW RATE (avg) (L/S-m^2)	PERMEANCE (avg) (m/Pa-S)	RESISTANCE (avg) (Pa-S/m)
25	0,0094	3.74×10^{-7}	$2.67 \times 10^{+6}$
50	0,0185	3.69×10^{-7}	$2.71 \times 10^{+6}$
75	0,0274	3.66×10^{-7}	$2.73 \times 10^{+6}$
100	0,0364	3.64×10^{-7}	$2.75 \times 10^{+6}$

EQUIVALENT LEAKAGE AREA:

ELA = 1.531×10^{-6} m^2

Diam. ELA = 1.39636 mm


SPECIMEN'S CURVES
Air flow vs static pressure diff.
16C
16D
AVG
16E
16B
16A
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0
20
40
60
80
100
120
STAT. PRESSURE DIFF. (SPECIMEN) (Pa)

MATERIAL NO.: 17

MATERIAL DESCRIPTION: GLASS WOOL INSULATION

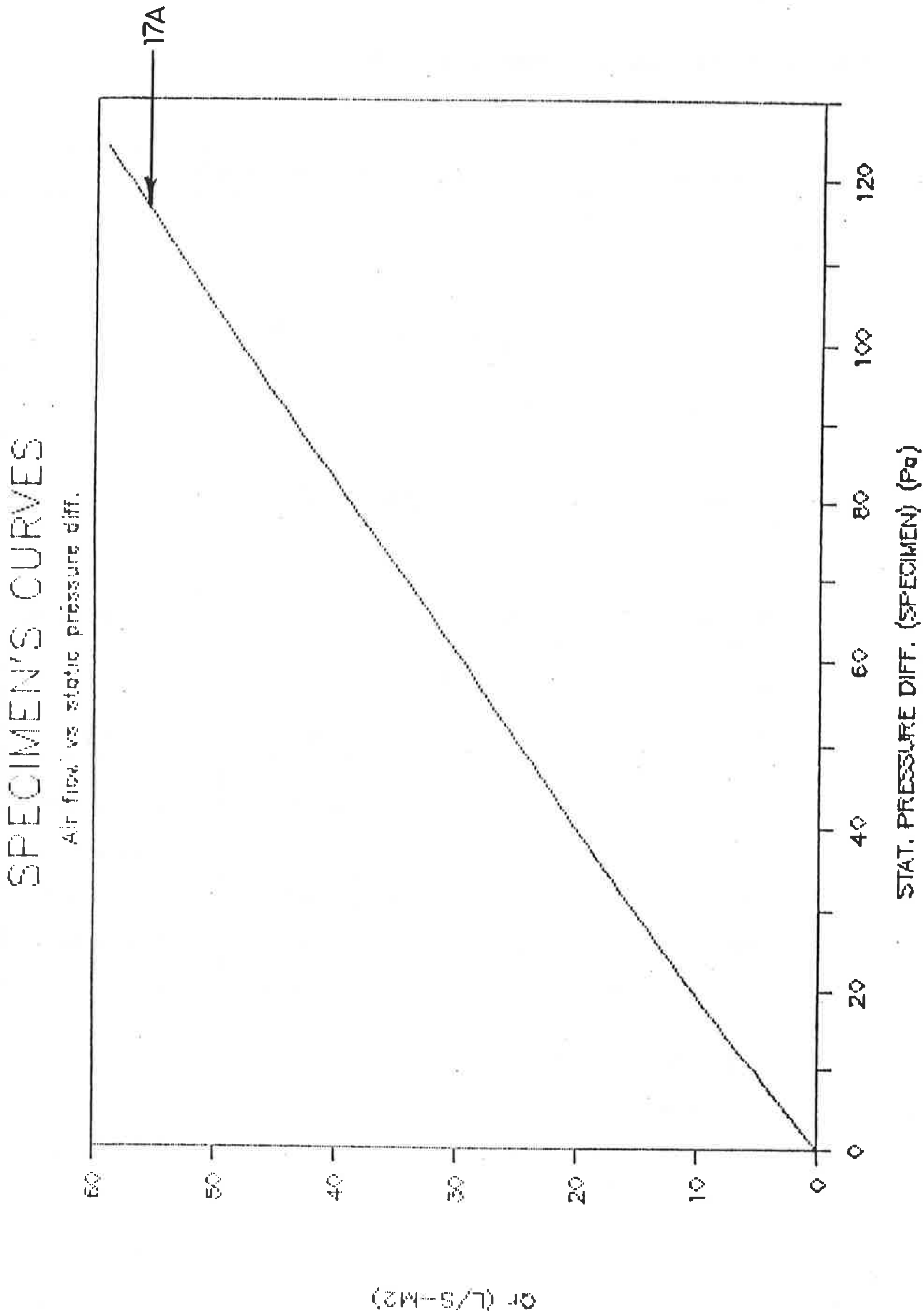
SPECIMEN	Q_S VERSUS P (L/S-m^2)
17 A	$Q_S = 0,61088 \ P^{0,94882}$
AVERAGE	$Q_S = 0,61088 \ P^{0,94882}$

STATIC PRESSURE DIFFERENTIAL ACROSS THE MATERIAL (Pa)	AIR FLOW RATE (avg) (L/S-m^2)	PERMEANCE (avg) (m/Pa-S)	RESISTANCE (avg) (Pa-S/m)
25	12,9524	5.18×10^{-4}	$1.93 \times 10^{+3}$
50	25,0020	5.00×10^{-4}	$2.00 \times 10^{+3}$
75	36,7327	4.90×10^{-4}	$2.04 \times 10^{+3}$
100	48,2612	4.83×10^{-4}	$2.07 \times 10^{+3}$

EQUIVALENT LEAKAGE AREA:

ELA = 2.180×10^{-3} m^2

Diam. ELA = 52,68163 mm


SPECIMEN'S CURVES
Air flow vs static pressure diff.
17A
STAT. PRESSURE DIFF. (SPECIMEN) (Pa)
qr (L/S-M2)
0
20
40
60
80
100
120
0
10
20
30
40
50
60

MATERIAL NO.: 18

MATERIAL DESCRIPTION: 8 mm PLYWOOD SHEATING

SPECIMEN	Q_S VERSUS P (L/S-m^2)
18 A	$Q_S = 0,00032 \; P^{0,94823}$
18 B	$Q_S = 0,00010 \; P^{0,89511}$
18 C	$Q_S = 0,00004 \; P^{1,000}$
18 D	NO MEASURABLE AIR FLOW
AVERAGE	$Q_S = 0,00011 \; P^{0,94382}$

STATIC PRESSURE DIFFERENTIAL ACROSS THE MATERIAL (Pa)	AIR FLOW RATE (avg) (L/S-m^2)	PERMEANCE (avg) (m/Pa-S)	RESISTANCE (avg) (Pa-S/m)
25	0,0024	9.43×10^{-8}	$1.06 \times 10^{+7}$
50	0,0045	9.07×10^{-8}	$1.10 \times 10^{+7}$
75	0,0067	8.87×10^{-8}	$1.13 \times 10^{+7}$
100	0,0087	8.73×10^{-8}	$1.15 \times 10^{+7}$

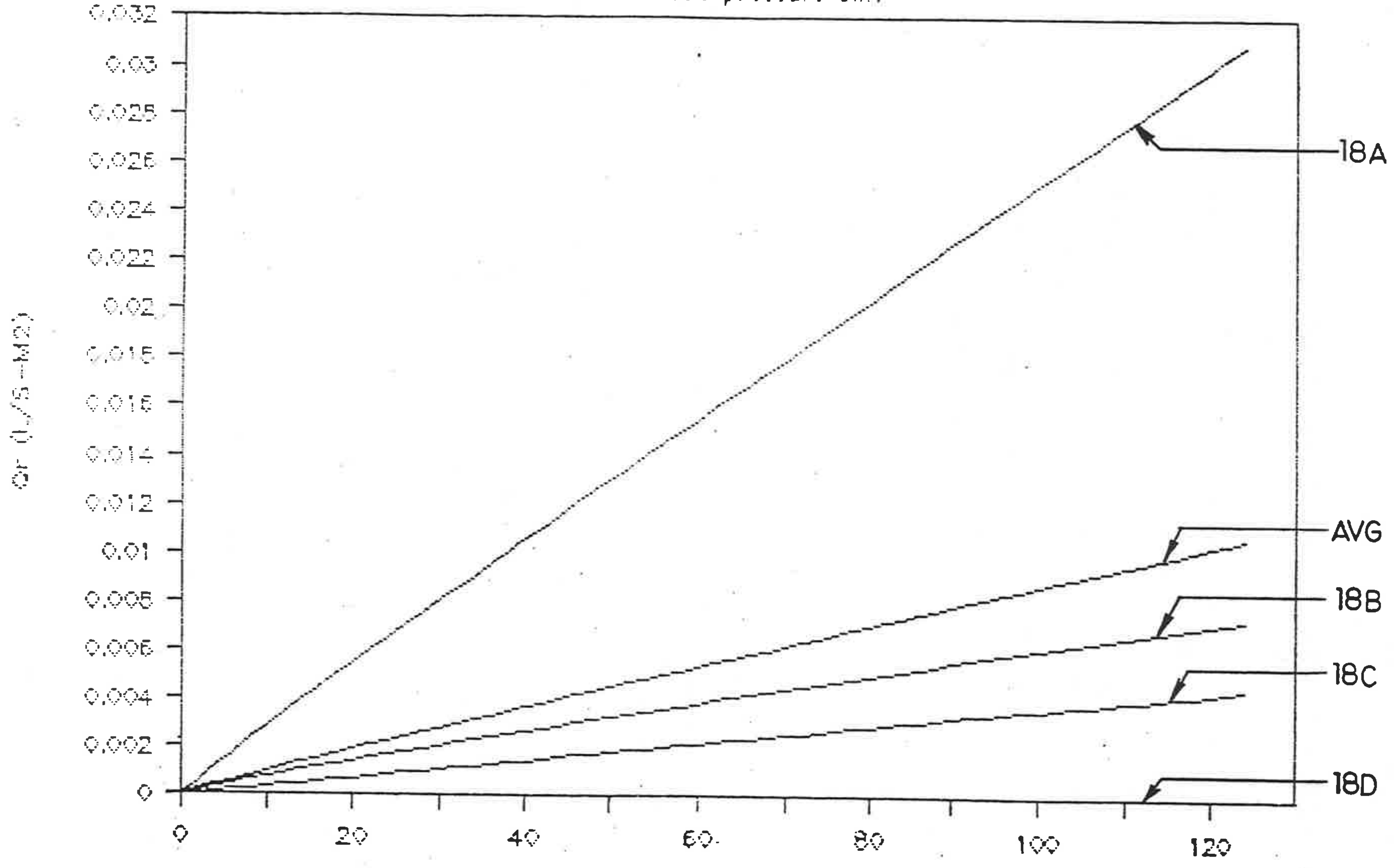
EQUIVALENT LEAKAGE AREA:

ELA = 3.987×10^{-7} m^2

Diam. ELA = 0.71251 mm

SPECIMEN'S CURVES

Air flow vs static pressure diff.



MATERIAL NO.: 20

MATERIAL DESCRIPTION: 11 mm FLAKE WOOD BOARD

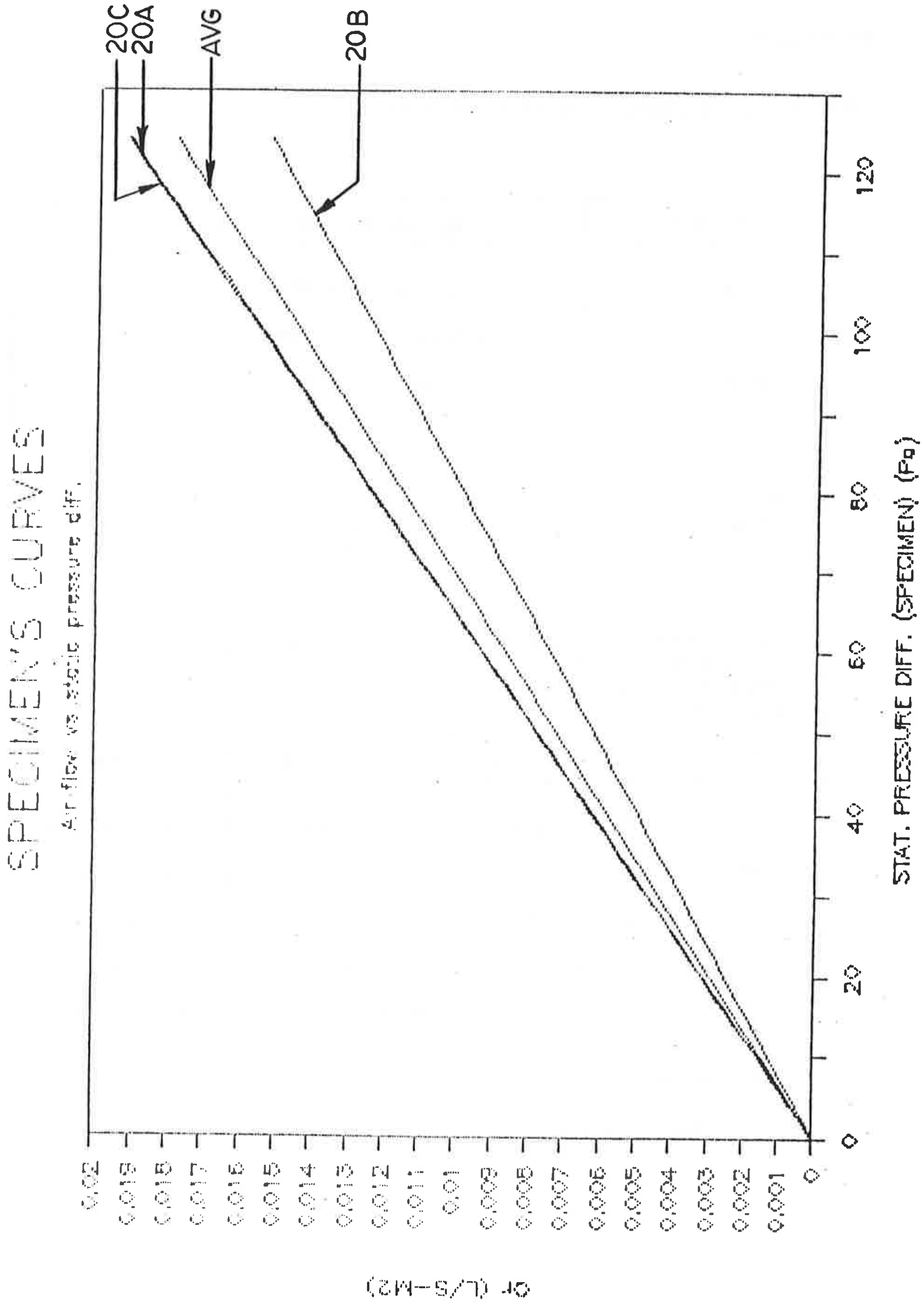
SPECIMEN	Q_S VERSUS P (L/S-m^2)
20 A	$Q_S = 0{,}00015\ P^{1{,}000}$
20 B	$Q_S = 0{,}00013\ P^{0{,}99567}$
20 C	$Q_S = 0{,}00015\ P^{0{,}99842}$
AVERAGE	$Q_S = 0{,}00145\ P^{0{,}99820}$

STATIC PRESSURE DIFFERENTIAL ACROSS THE MATERIAL (Pa)	AIR FLOW RATE (avg) (L/S-m^2)	PERMEANCE (avg) (m/Pa-S)	RESISTANCE(avg) (Pa-S/m)
25	0,0036	1.45×10^{-7}	$6.91 \times 10^{+6}$
50	0,0072	1.45×10^{-7}	$6.92 \times 10^{+6}$
75	0,0108	1.45×10^{-7}	$6.92 \times 10^{+6}$
100	0,0144	1.44×10^{-7}	$6.92 \times 10^{+6}$

EQUIVALENT LEAKAGE AREA:

ELA = 5.822×10^{-7} m^2

Diam. ELA = 0.86100 mm


SPECIMEN'S CURVES
Air flow vs static pressure diff.
20C
20A
AVG
20B
STAT. PRESSURE DIFF. (SPECIMEN) (Pa)
0
20
40
60
80
100
120
0
0.001
0.002
0.003
0.004
0.005
0.006
0.007
0.008
0.009
0.01
0.011
0.012
0.013
0.014
0.015
0.016
0.017
0.018
0.019
0.02
Qr (L/S-M2)

MATERIAL NO.: 21

MATERIAL DESCRIPTION: 16 mm FLAKE WOOD BOARD

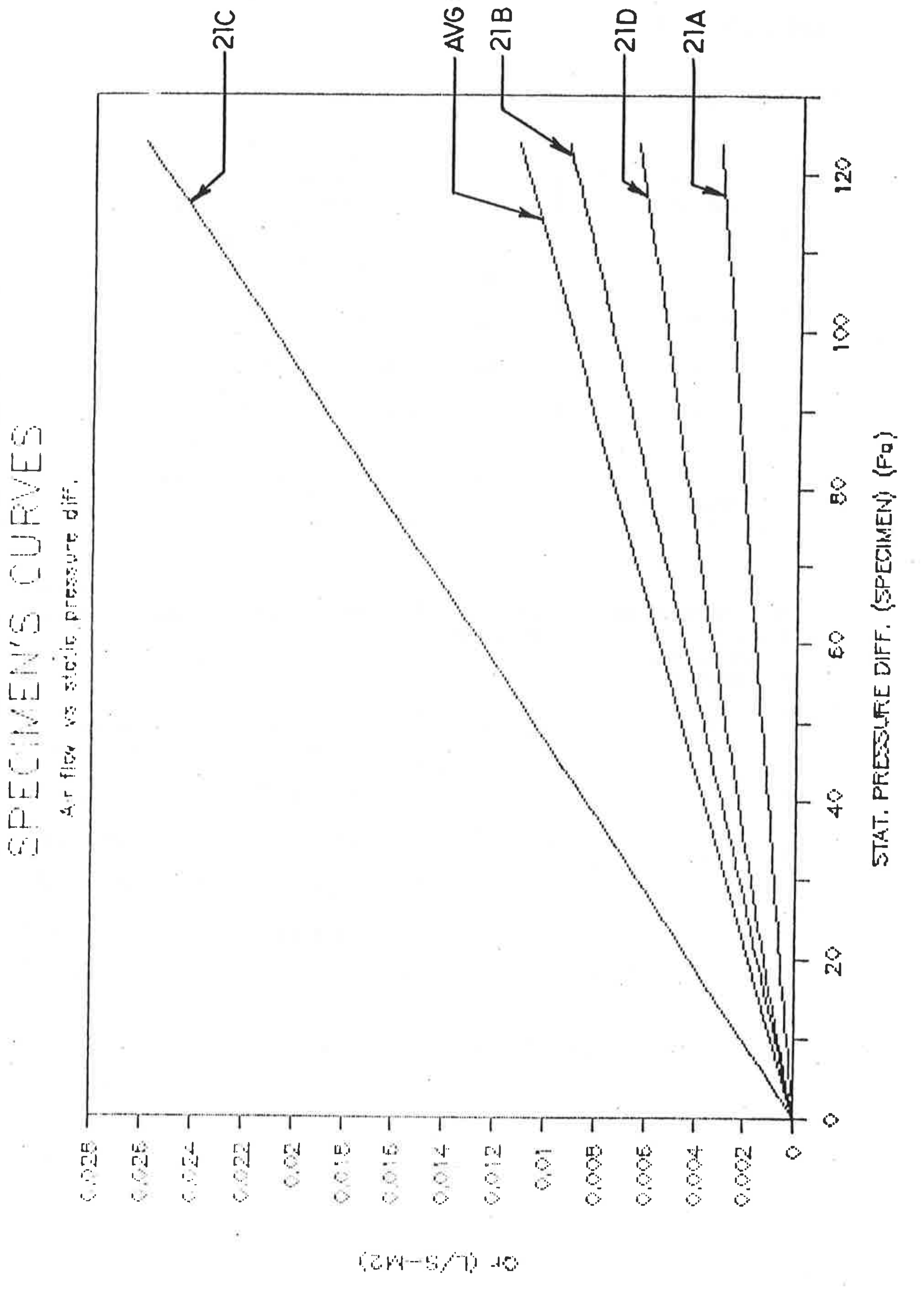
SPECIMEN	Q_S VERSUS P (L/S-m^2)
21 A	$Q_S = 0,00004 \; P^{0,92834}$
21 B	$Q_S = 0,00007 \; P^{1,000}$
21 C	$Q_S = 0,00022 \; P^{0,99667}$
21 D	$Q_S = 0,00008 \; P^{0,90893}$
AVERAGE	$Q_S = 0,00010 \; P^{0,97861}$

STATIC PRESSURE DIFFERENTIAL ACROSS THE MATERIAL (Pa)	AIR FLOW RATE (avg) (L/S-m^2)	PERMEANCE (avg) (m/Pa-S)	RESISTANCE (avg) (Pa-S/m)
25	0,0024	9.41×10^{-8}	$1.06 \times 10^{+7}$
50	0,0046	9.27×10^{-8}	$1.08 \times 10^{+7}$
75	0,0069	9.19×10^{-8}	$1.09 \times 10^{+7}$
100	0,0091	9.13×10^{-8}	$1.10 \times 10^{+7}$

EQUIVALENT LEAKAGE AREA:

ELA = 3.851×10^{-7} m^2

Diam. ELA = 0.70021 mm


SPECIMEN'S CURVES
Air flow vs static pressure diff.
21C
AVG
21B
21D
21A
0
20
40
60
80
100
120
STAT. PRESSURE DIFF. (SPECIMEN) (Pa)
0
0.002
0.004
0.006
0.008
0.01
0.012
0.014
0.016
0.018
0.02
0.022
0.024
0.026
0.028
Qr (L/S-M2)

MATERIAL NO.: 22

MATERIAL DESCRIPTION: 12.7 mm PARTICULE BOARD

SPECIMEN	Q_S VERSUS P (L/S-m^2)
22 A	$Q_S = 0{,}00021 \; P^{0{,}98805}$
22 B	$Q_S = 0{,}00021 \; P^{1{,}000}$
22 C	$Q_S = 0{,}00021 \; P^{0{,}99908}$
AVERAGE	$Q_S = 0{,}00021 \; P^{0{,}99578}$

STATIC PRESSURE DIFFERENTIAL ACROSS THE MATERIAL (Pa)	AIR FLOW RATE (avg) (L/S-m^2)	PERMEANCE (avg) (m/Pa-S)	RESISTANCE (avg) (Pa-S/m)
25	0,0052	2.08×10^{-7}	$4.81 \times 10^{+6}$
50	0,0104	2.07×10^{-7}	$4.83 \times 10^{+6}$
75	0,0155	2.07×10^{-7}	$4.84 \times 10^{+6}$
100	0,0207	2.07×10^{-7}	$4.84 \times 10^{+6}$

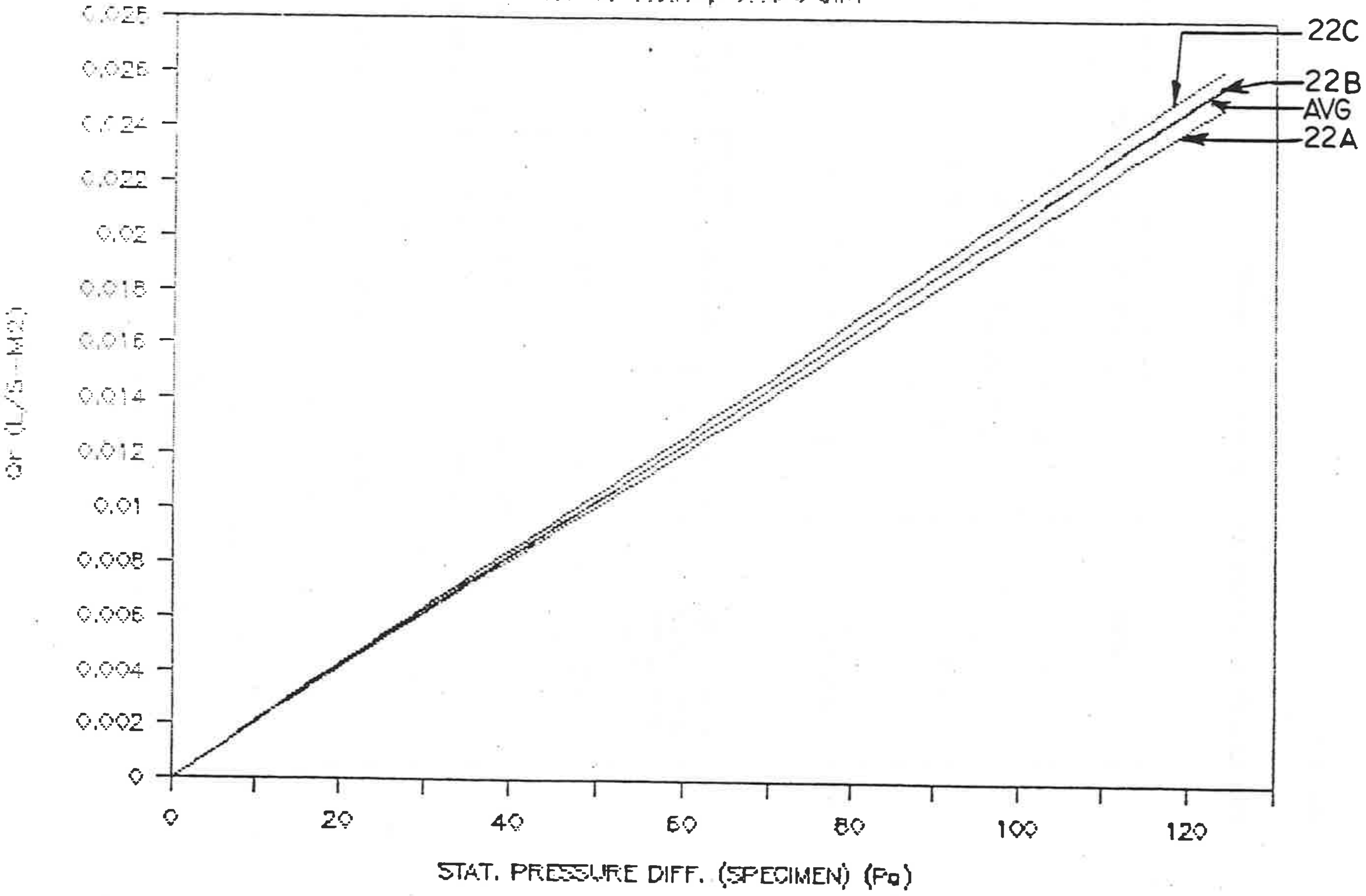
EQUIVALENT LEAKAGE AREA:

ELA = 8.372×10^{-7} m^2

Diam. ELA = 1.03246 mm

SPECIMEN'S CURVES

Air flow vs static pressure diff.



MATERIAL NO.: 23

MATERIAL DESCRIPTION: 16 mm PARTICLE BOARD

SPECIMEN	Q_S VERSUS P (L/S-m^2)
23 A	$Q_S = 0,00045\ P^{1,000}$
23 B	$Q_S = 0,00058\ P^{0,77583}$
23 C	$Q_S = 0,00051\ P^{0,96908}$
23 D	$Q_S = 0,00029\ P^{0,98931}$
AVERAGE	$Q_S = 0,00043\ P^{0,94942}$

STATIC PRESSURE DIFFERENTIAL ACROSS THE MATERIAL (Pa)	AIR FLOW RATE (avg) (L/S-m^2)	PERMEANCE (avg) (m/Pa-S)	RESISTANCE (avg) (Pa-S/m)
25	0,0092	3.67×10^{-7}	$2.73 \times 10^{+6}$
50	0,0177	3.54×10^{-7}	$2.82 \times 10^{+6}$
75	0,0260	3.47×10^{-7}	$2.88 \times 10^{+6}$
100	0,0342	3.42×10^{-7}	$2.92 \times 10^{+6}$

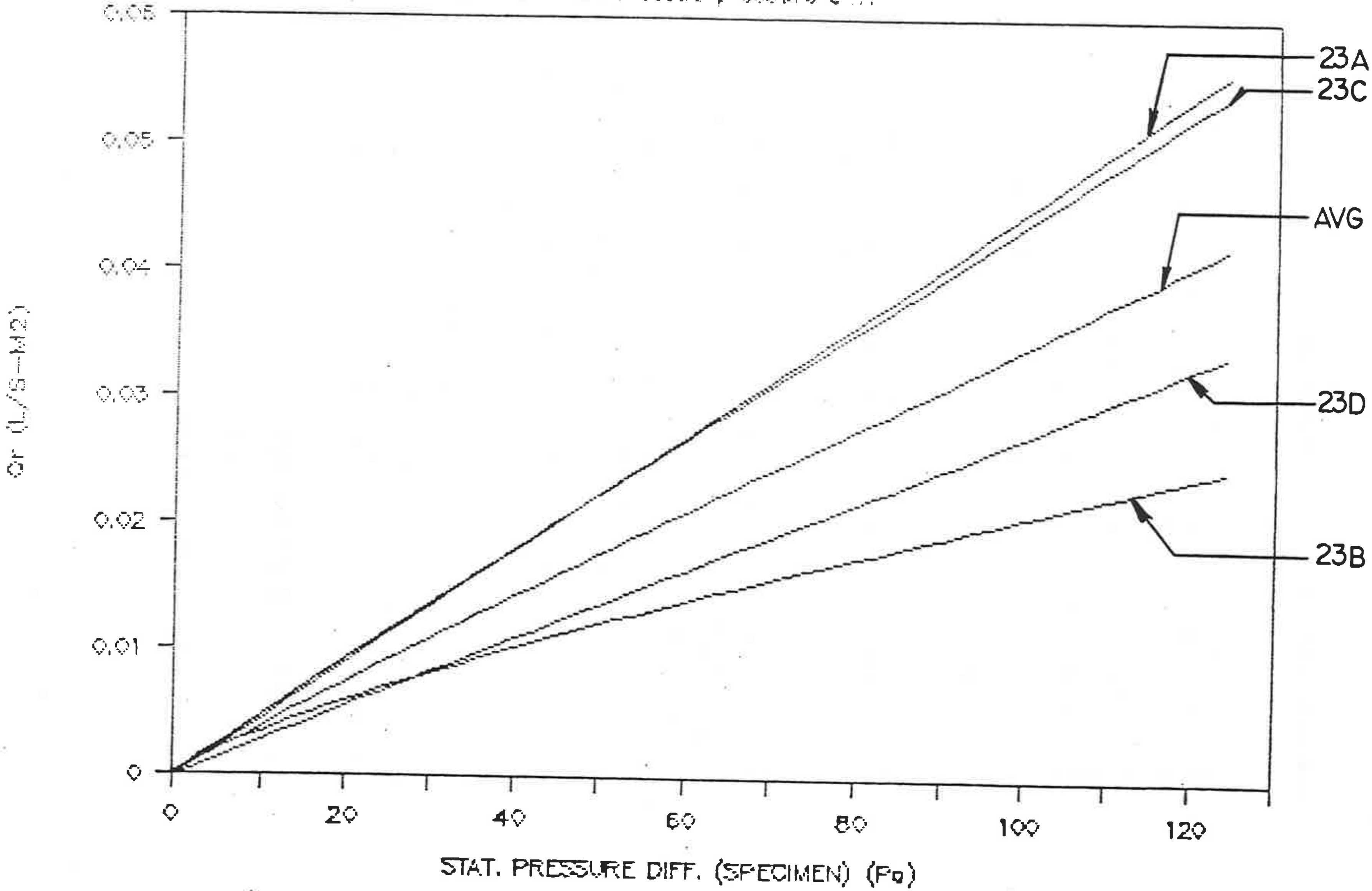
EQUIVALENT LEAKAGE AREA:

$\text{ELA} = 1.543 \times 10^{-6}\ m^2$

Diam. ELA = 1.40150 mm

SPECIMEN'S CURVES

Air flow vs static pressure diff.



MATERIAL NO.: 24

MATERIAL DESCRIPTION: 11 mm PLAIN FIBERBOARD

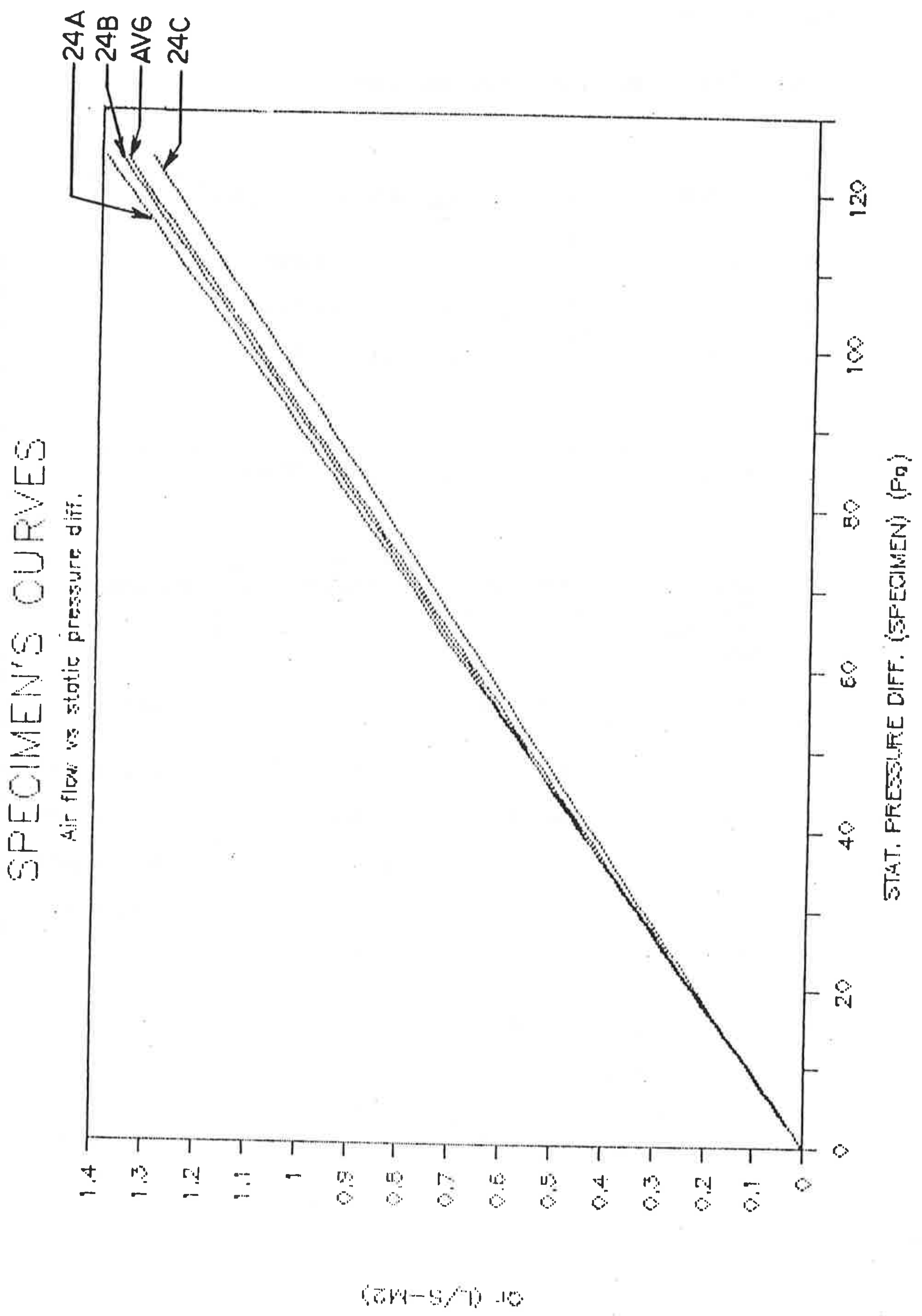
SPECIMEN	Q_S VERSUS P (L/S-m^2)
24 A	$Q_S = 0,01124 \ P^{1,000}$
24 B	$Q_S = 0,01183 \ P^{0,98486}$
24 C	$Q_S = 0,01136 \ P^{0,98344}$
AVERAGE	$Q_S = 0,01147 \ P^{0,98955}$

STATIC PRESSURE DIFFERENTIAL ACROSS THE MATERIAL (Pa)	AIR FLOW RATE (avg) (L/S-m^2)	PERMEANCE (avg) (m/Pa-S)	RESISTANCE (avg) (Pa-S/m)
25	0,2773	1.11×10^{-5}	$9.02 \times 10^{+4}$
50	0,5505	1.10×10^{-5}	$9.08 \times 10^{+4}$
75	0,8223	1.10×10^{-5}	$9.12 \times 10^{+4}$
100	1,0931	1.09×10^{-5}	$9.15 \times 10^{+4}$

EQUIVALENT LEAKAGE AREA:

ELA = 4.495×10^{-5} m^2

Diam. ELA = 7.56543 mm


SPECIMEN'S CURVES
Air flow vs static pressure diff.
24A
24B
AVG
24C
STAT. PRESSURE DIFF. (SPECIMEN) (Pa)
0
20
40
60
80
100
120
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
1.1
1.2
1.3
1.4
(L/S-M2)

MATERIAL NO.: 25

MATERIAL DESCRIPTION: 11 mm FIBERBOARD (asphalt coated)

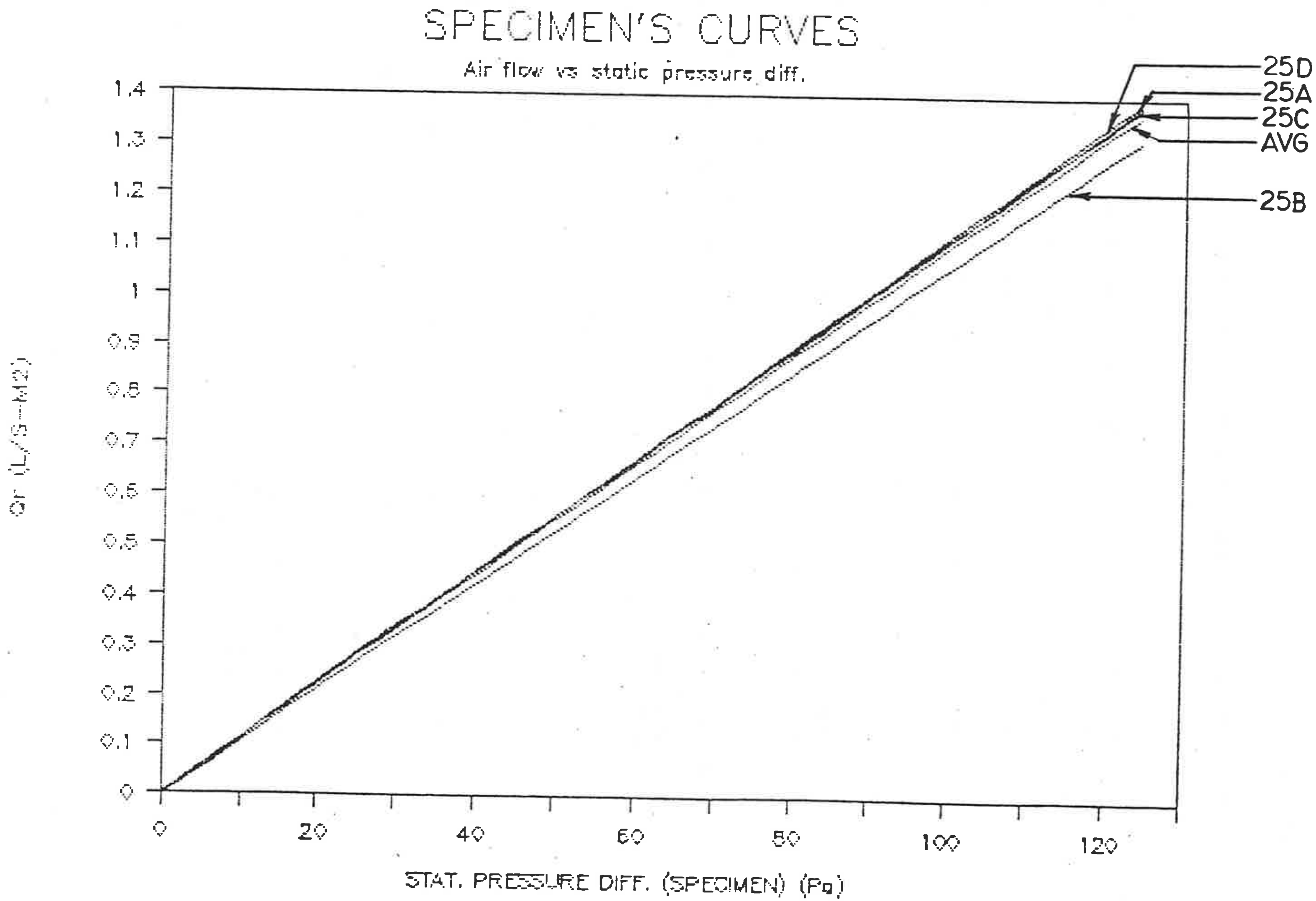
SPECIMEN	Q_S VERSUS P (L/S-m^2)
25 A	$Q_S = 0{,}01164\ P^{0{,}99103}$
25 B	$Q_S = 0{,}01061\ P^{1{,}000}$
25 C	$Q_S = 0{,}01147\ P^{0{,}99352}$
25 D	$Q_S = 0{,}01136\ P^{0{,}99745}$
AVERAGE	$Q_S = 0{,}01127\ P^{0{,}99545}$

STATIC PRESSURE DIFFERENTIAL ACROSS THE MATERIAL (Pa)	AIR FLOW RATE (avg) (L/S-m^2)	PERMEANCE (avg) (m/Pa-S)	RESISTANCE(avg) (Pa-S/m)
25	0,2776	1.11×10^{-5}	$9.01 \times 10^{+4}$
50	0,5534	1.11×10^{-5}	$9.04 \times 10^{+4}$
75	0,8285	1.10×10^{-5}	$9.05 \times 10^{+4}$
100	1,1032	1.10×10^{-5}	$9.06 \times 10^{+4}$

EQUIVALENT LEAKAGE AREA:

ELA = 4.476×10^{-5} m^2

Diam. ELA = 7.54892 mm


SPECIMEN'S CURVES
Air flow vs static pressure diff.
25D
25A
25C
AVG
25B
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Qr (L/S-M2)
0
20
40
60
80
100
120
STAT. PRESSURE DIFF. (SPECIMEN) (Pa)

MATERIAL NO.: 26

MATERIAL DESCRIPTION: TONGUE AND GROOVE PLANKS

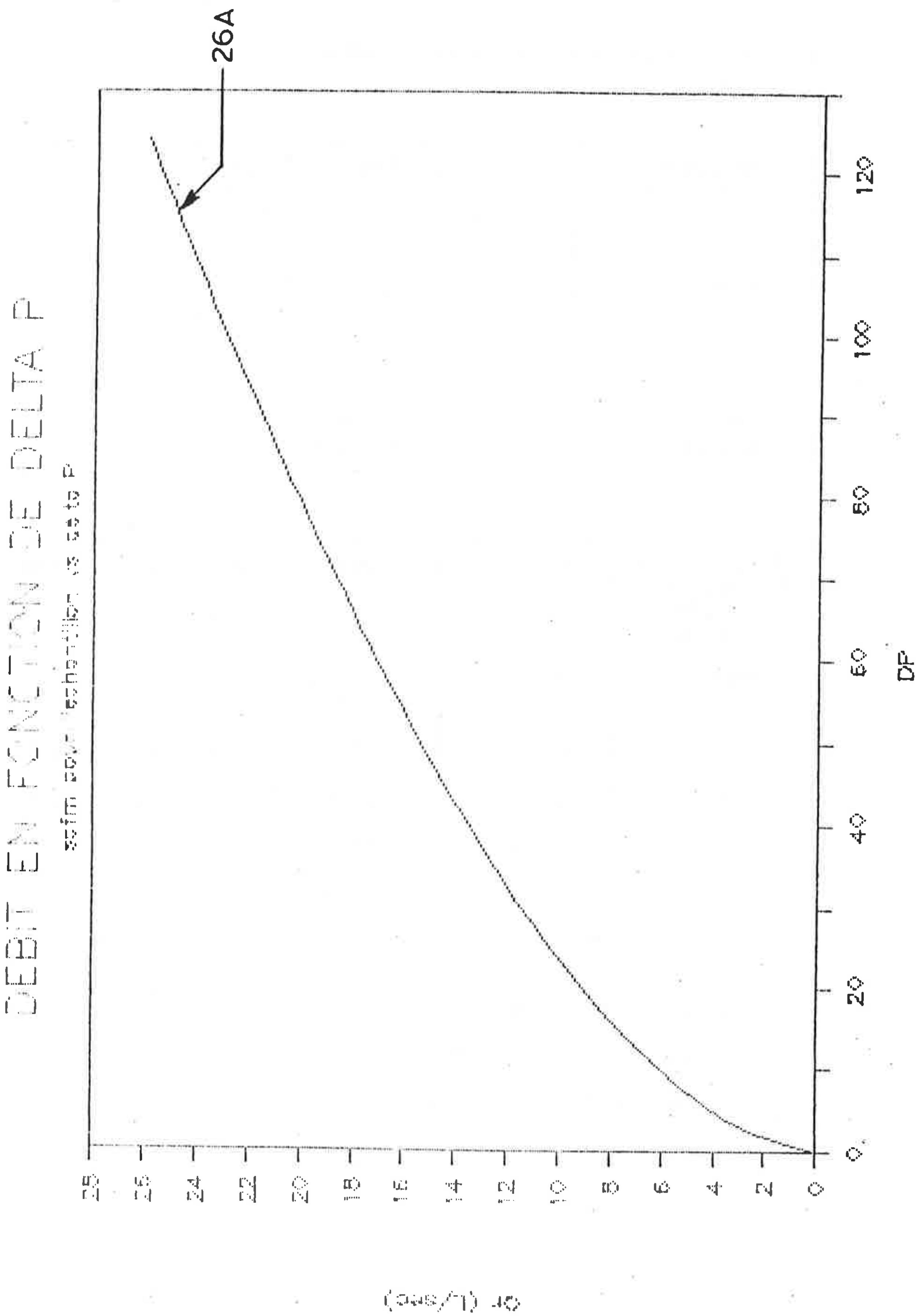
SPECIMEN	Q_S VERSUS P (L/S-m^2)
26 A	$Q_S = 1,67093 \ P^{0,56449}$
AVERAGE	$Q_S = 1,67093 \ P^{0,56449}$

STATIC PRESSURE DIFFERENTIAL ACROSS THE MATERIAL (Pa)	AIR FLOW RATE (avg) (L/S-m^2)	PERMEANCE (avg) (m/Pa-S)	RESISTANCE (avg) (Pa-S/m)
25	10,2820	4.11×10^{-4}	$2.43 \times 10^{+3}$
50	15,2057	3.04×10^{-4}	$3.29 \times 10^{+3}$
75	19,1165	2.55×10^{-4}	$3.92 \times 10^{+3}$
100	22,4872	2.25×10^{-4}	$4.45 \times 10^{+3}$

EQUIVALENT LEAKAGE AREA:

ELA = 2.461×10^{-3} m^2

Diam. ELA = 55.97512 mm


DEBIT EN FONCTION DE DELTA P
26A
DP
Qr (L/sec)
0
20
40
60
80
100
120
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28

MATERIAL NO.: 29

MATERIAL DESCRIPTION: EXPANDED POLYSTYRENE BOARD (TYPE 1)

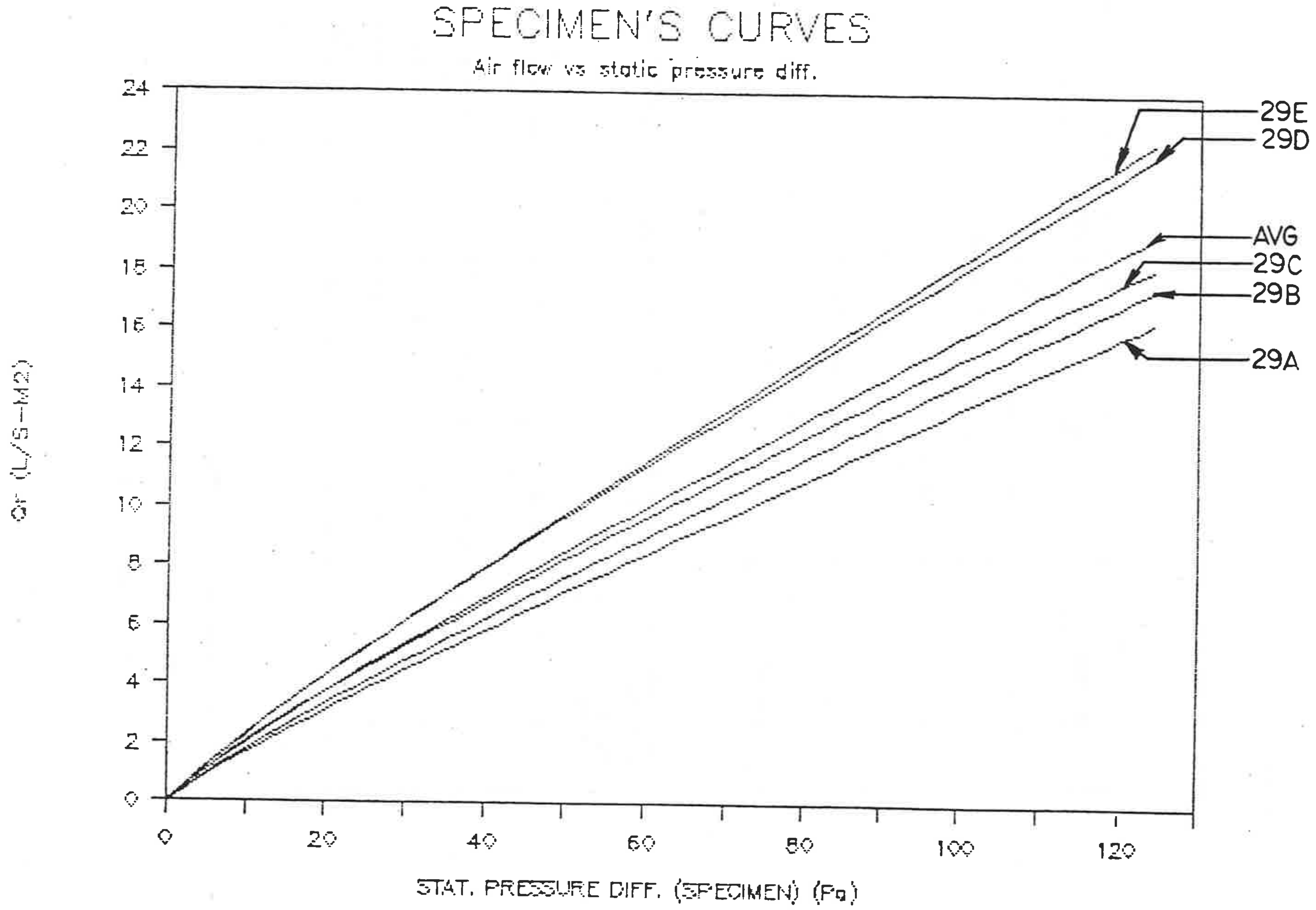
SPECIMEN	Q_S VERSUS P (L/S-m^2)
29 A	$Q_S = 0{,}20323\ P^{0{,}90981}$
29 B	$Q_S = 0{,}21714\ P^{0{,}90988}$
29 C	$Q_S = 0{,}27323\ P^{0{,}87085}$
29 D	$Q_S = 0{,}28870\ P^{0{,}89790}$
29 E	$Q_S = 0{,}27668\ P^{0{,}91140}$
AVERAGE	$Q_S = 0{,}25136\ P^{0{,}89991}$

STATIC PRESSURE DIFFERENTIAL ACROSS THE MATERIAL (Pa)	AIR FLOW RATE (avg) (L/S-m^2)	PERMEANCE (avg) (m/Pa-S)	RESISTANCE(avg) (Pa-S/m)
25	4,5532	1.82×10^{-4}	$5.49 \times 10^{+3}$
50	8,4960	1.70×10^{-4}	$5.89 \times 10^{+3}$
75	12,2372	1.63×10^{-4}	$6.13 \times 10^{+3}$
100	15,8532	1.59×10^{-4}	$6.31 \times 10^{+3}$

EQUIVALENT LEAKAGE AREA:

ELA = 8.014×10^{-4} m^2

Diam. ELA = 31.94281 mm


SPECIMEN'S CURVES
Air flow vs static pressure diff.
Qr (L/S-M2)
STAT. PRESSURE DIFF. (SPECIMEN) (Pa)
0
2
4
6
8
10
12
14
16
18
20
22
24
0
20
40
60
80
100
120
29E
29D
AVG
29C
29B
29A

MATERIAL NO.: 30

MATERIAL DESCRIPTION: EXPANDED POLYSTYRENE BOARD (TYPE 2)

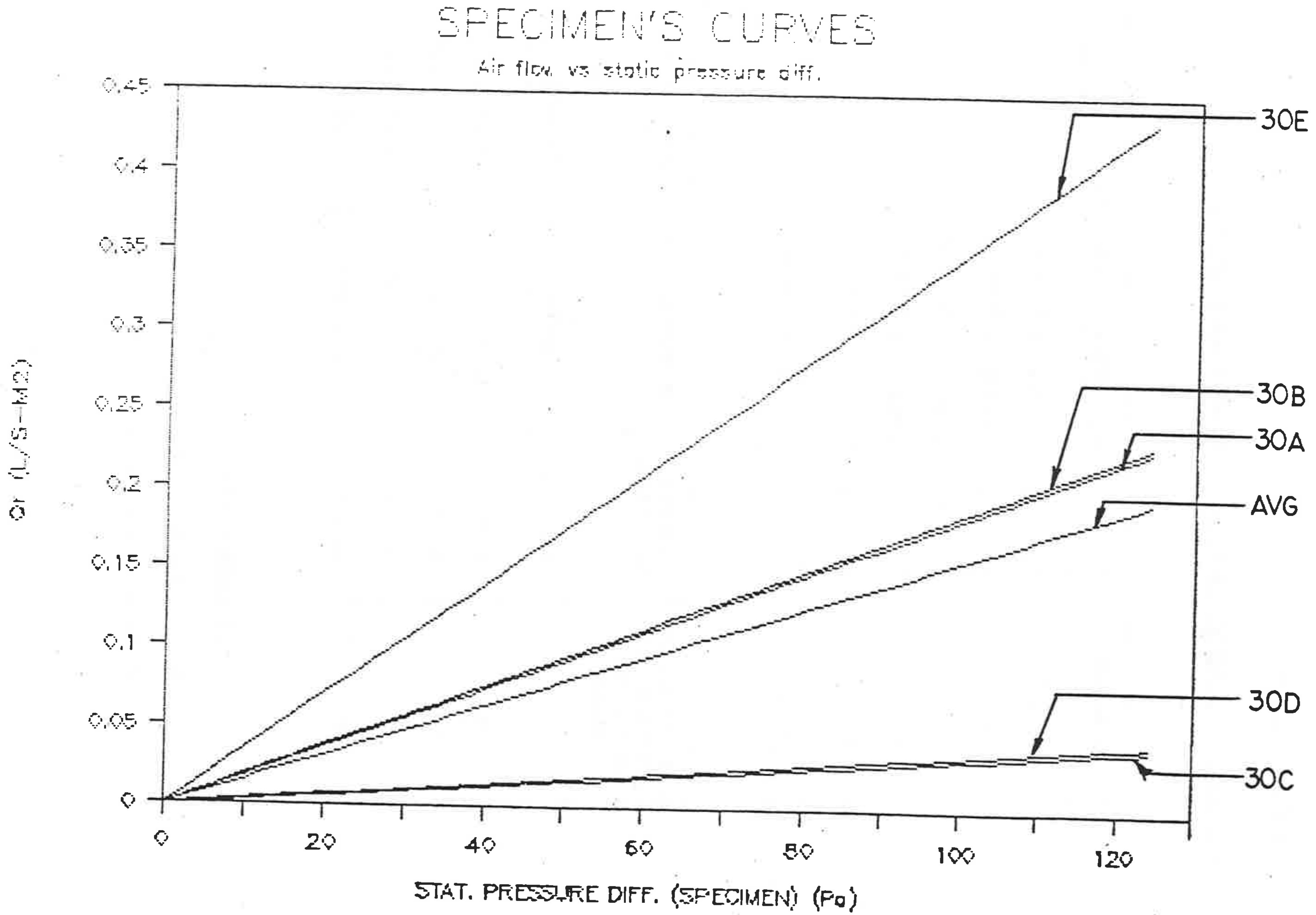
SPECIMEN	Q_S VERSUS P (L/S-m^2)
30 A	$Q_S = 0{,}00188 \; P^{0{,}99553}$
30 B	$Q_S = 0{,}00199 \; P^{0{,}98680}$
30 C	$Q_S = 0{,}00032 \; P^{0{,}99902}$
30 D	$Q_S = 0{,}00039 \; P^{0{,}97422}$
30 E	$Q_S = 0{,}00357 \; P^{0{,}99643}$
AVERAGE	$Q_S = 0{,}00163 \; P^{0{,}99304}$

STATIC PRESSURE DIFFERENTIAL ACROSS THE MATERIAL (Pa)	AIR FLOW RATE (avg) (L/S-m^2)	PERMEANCE (avg) (m/Pa-S)	RESISTANCE (avg) (Pa-S/m)
25	0,0399	1.59×10^{-6}	$6.27 \times 10^{+5}$
50	0,0794	1.59×10^{-6}	$6.30 \times 10^{+5}$
75	0,1187	1.58×10^{-6}	$6.32 \times 10^{+5}$
100	0,1579	1.58×10^{-6}	$6.33 \times 10^{+5}$

EQUIVALENT LEAKAGE AREA:

ELA = 6.443×10^{-6} m^2

Diam. ELA = 2.86414 mm


SPECIMEN'S CURVES
Air flow vs static pressure diff.
Qr (L/S-M2)
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
20
40
60
80
100
120
STAT. PRESSURE DIFF. (SPECIMEN) (Pa)
30E
30B
30A
AVG
30D
30C

MATERIAL NO.: 33

MATERIAL DESCRIPTION: GLASS FIBER RIGID INSULATION BOARD
(with a spunbonded olefin film on one side)

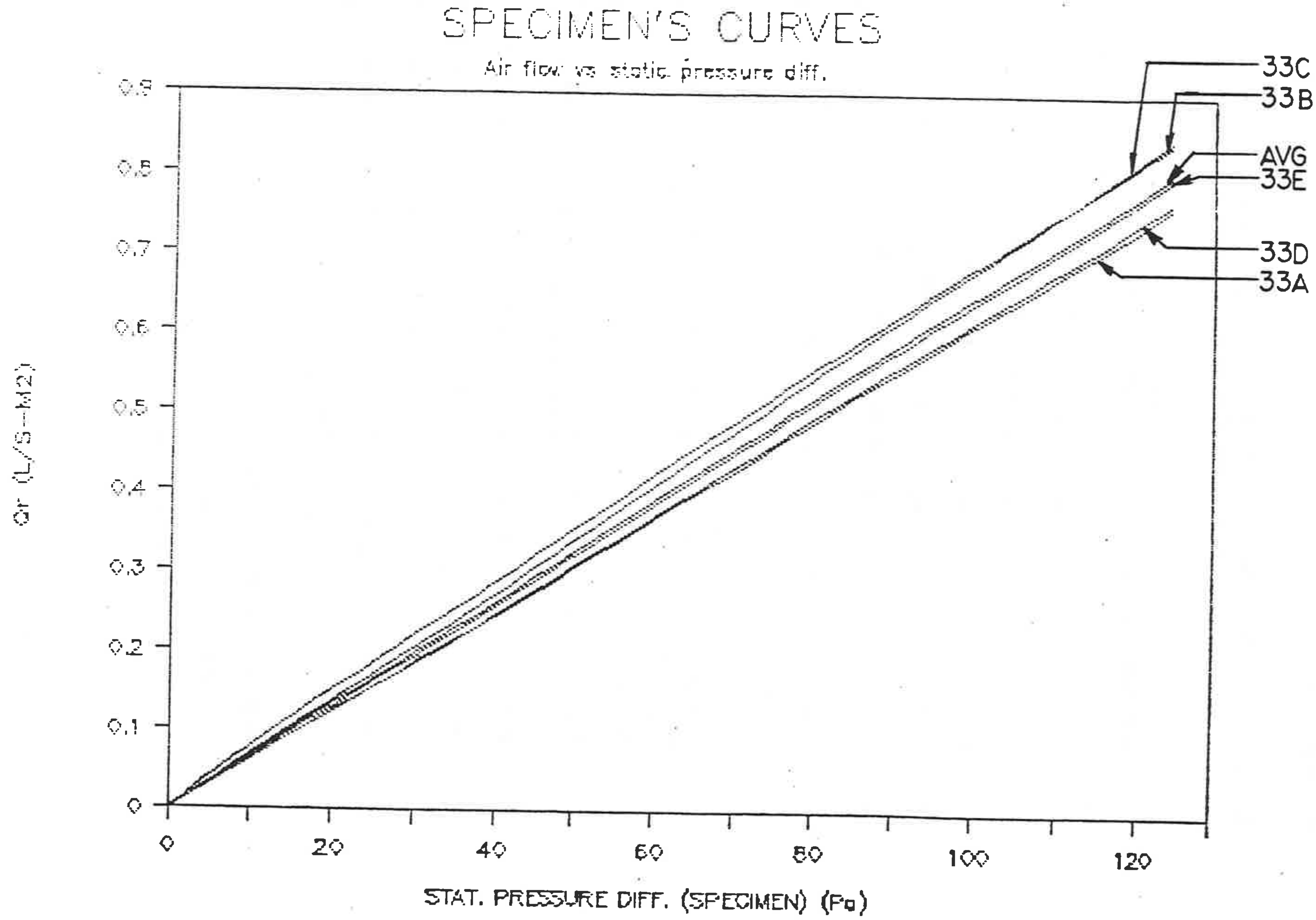
SPECIMEN	Q_S VERSUS P (L/S-m^2)
33 A	$Q_S = 0{,}00613\ P^{1{,}000}$
33 B	$Q_S = 0{,}00888\ P^{0{,}94408}$
33 C	$Q_S = 0{,}00683\ P^{0{,}99986}$
33 D	$Q_S = 0{,}00618\ P^{1{,}000}$
33 E	$Q_S = 0{,}00651\ P^{0{,}99682}$
AVERAGE	$Q_S = 0{,}00688\ P^{0{,}98713}$

STATIC PRESSURE DIFFERENTIAL ACROSS THE MATERIAL (Pa)	AIR FLOW RATE (avg) (L/S-m^2)	PERMEANCE (avg) (m/Pa-S)	RESISTANCE(avg) (Pa-S/m)
25	0,1650	6.60×10^{-6}	$1.52 \times 10^{+5}$
50	0,3270	6.54×10^{-6}	$1.53 \times 10^{+5}$
75	0,4880	6.51×10^{-6}	$1.54 \times 10^{+5}$
100	0,6482	6.48×10^{-6}	$1.54 \times 10^{+5}$

EQUIVALENT LEAKAGE AREA:

ELA = 2.681×10^{-5} m^2

Diam. ELA = 5.84205 mm


SPECIMEN'S CURVES
Air flow vs static pressure diff.
33C
33B
AVG
33E
33D
33A
Qr (L/S-M2)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
0
20
40
60
80
100
120
STAT. PRESSURE DIFF. (SPECIMEN) (Pa)

MATERIAL NO.: 34

MATERIAL DESCRIPTION: VERMICULITE LOOSE FILL INSULATION

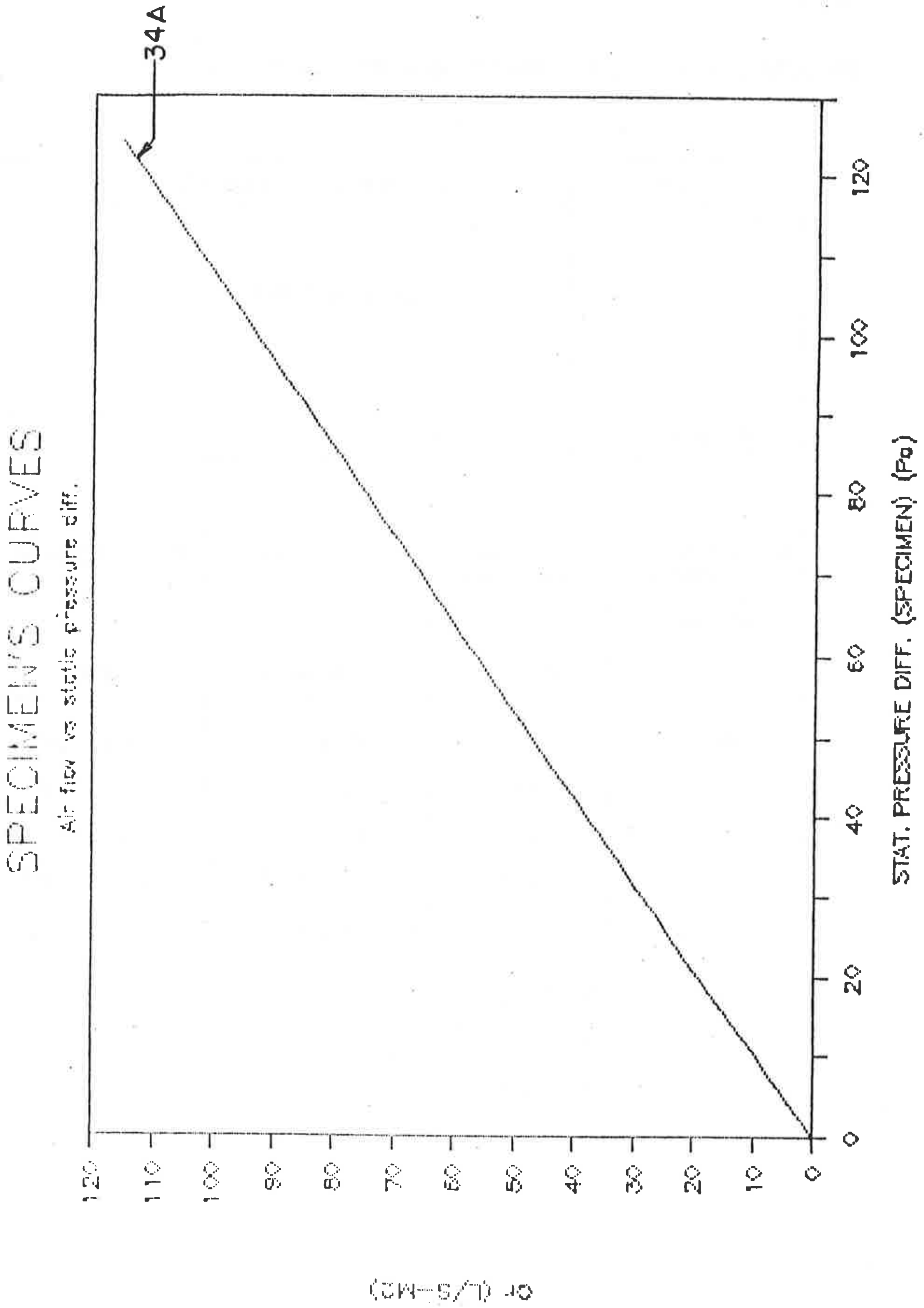
SPECIMEN	Q_S VERSUS P (L/S-m^2)
34 A	$Q_S = 1{,}02962 \ P^{0{,}97888}$
AVERAGE	$Q_S = 1{,}02962 \ P^{0{,}97888}$

STATIC PRESSURE DIFFERENTIAL ACROSS THE MATERIAL (Pa)	AIR FLOW RATE (avg) (L/S-m^2)	PERMEANCE (avg) (m/Pa-S)	RESISTANCE (avg) (Pa-S/m)
25	24,0490	9.62×10^{-4}	$1.04 \times 10^{+3}$
50	47,3991	9.48×10^{-4}	$1.05 \times 10^{+3}$
75	70,4926	9.40×10^{-4}	$1.06 \times 10^{+3}$
100	93,4209	9.34×10^{-4}	$1.07 \times 10^{+3}$

EQUIVALENT LEAKAGE AREA:

ELA = 3.937×10^{-3} m^2

Diam. ELA = 70.80293 mm


SPECIMEN'S CURVES
Air flow vs static pressure diff.
34A
STAT. PRESSURE DIFF. (SPECIMEN) (Pa)
0
20
40
60
80
100
120
10
30
50
70
90
110