Standard Test Method for Total Hemispherical Emittance of Surfaces From 20 to 1400°C[1]

This standard is issued under the fixed designation C 835; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This calorimetric test method covers the determination of total hemispherical emittance of metal and graphite surfaces and coated metal surfaces from approximately 20 to 1400°C. The upper-use temperature is limited only by the characteristics (for example, melting temperature, vapor pressure) of the specimen and the design limits of the test facility. This test method has been demonstrated for use up to 1400°C.

1.2 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.* For specific hazard statements, see Section 7.

2. Referenced Documents

2.1 *ASTM Standards:*

C 168 Terminology Relating to Thermal Insulating Materials[2]

E 230 Temperature-Electromotive Force (EMF) Tables for Standardized Thermocouples[3]

E 691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method[4]

3. Terminology

3.1 *Definitions*—The terms and symbols are as defined in Terminology C 168 with exceptions included as appropriate.

3.2 *Symbols:Symbols:*

e_i = error in the variable i, ± %,
ϵ_1 = total hemispherical emittance of heated specimen, dimensionless,
ϵ_2 = total hemispherical emittance of bell jar inner surface, dimensionless,
σ = Stefan-Boltzmann constant,
= 5.669×10^{-8} W/m^2·K^4,
Q = heat flow rate, W,
T_1 = temperature of heated specimen, K,
T_2 = temperature of bell jar inner surface, K,
A_1 = surface area of specimen over which heat generation is measured, m^2,
A_2 = surface area of bell jar inner surface, m^2,
F = the gray body shape factor, which includes the effect of geometry and the departure of real surfaces from blackbody conditions, dimensionless, and
Pa = absolute pressure, pascal (N/m^2). One pascal is equivalent to 0.00750 mm Hg.

4. Summary of Test Method

4.1 A strip specimen of the material, approximately 13 mm wide and 250 mm long, is placed in an evacuated chamber and is directly heated with an electric current to the temperature at which the emittance measurement is desired. The power dissipated over a small central region of the specimen and the temperature of this region are measured. Using the Stefan-Boltzmann equation, this power is equated to the radiative heat transfer to the surroundings and, with the measured temperature, is used to calculate the value of the total hemispherical emittance of the specimen surface.

5. Significance and Use

5.1 The emittance as measured by this test method can be used in the calculation of radiant heat transfer from surfaces that are representative of the tested specimens, and that are within the temperature range of the tested specimens.

5.2 This test method can be used to determine the effect of service conditions on the emittance of materials. In particular, the use of this test method with furnace exposure (time at temperature) of the materials commonly used in all-metallic insulations can determine the effects of oxidation on emittance.

5.3 The measurements described in this test method are conducted in a vacuum environment. Usually this condition will provide emittance values that are applicable to materials used under other conditions, such as in an air environment. However, it must be recognized that surface properties of materials used in air or other atmospheres may be different. In addition, preconditioned surfaces, as described in 5.2, may be

[1] This test method is under the jurisdiction of ASTM Committee C-16 on Thermal Insulation and is the direct responsibility of Subcommittee C16.30 on Thermal Measurements.

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[2] *Annual Book of ASTM Standards*, Vol 04.06.

[3] *Annual Book of ASTM Standards*, Vol 14.03.

[4] *Annual Book of ASTM Standards*, Vol 14.02.

altered in a vacuum environment because of vacuum stripping of absorbed gases and other associated vacuum effects. Thus, emittances measured under vacuum may have values that differ from those that exist in air, and the user must be aware of this situation. With these qualifications in mind, emittance obtained by this test method may be applied to predictions of thermal transference.

5.4 Several assumptions are made in the derivation of the emittance calculation as described in this test method. They are that:

5.4.1 The enclosure is a blackbody emitter at a uniform temperature,

5.4.2 The total hemispherical absorptance of the completely diffuse blackbody radiation at the temperature of the enclosure is equal to the total hemispherical emittance of the specimen at its temperature, and

5.4.3 There is no heat loss from the test section by convection or conduction. For most materials tested by the procedures as described in this test method, the effects of these assumptions are small and either neglected or corrections are made to the measured emittance.

5.5 For satisfactory results in conformance with this test method, the principles governing the size, construction, and use of apparatus described in this test method should be followed. If these principles are followed, any measured value obtained by the use of this test method is expected to be accurate to within ±5 %. If the results are to be reported as having been obtained by this test method, all of the requirements prescribed in this test method shall be met.

5.6 It is not practical in a test method of this type to establish details of construction and procedure to cover all contingencies that might offer difficulties to a person without technical knowledge concerning the theory of heat transfer, temperature measurements, and general testing practices. Standardization of this test method does not reduce the need for such technical knowledge. It is recognized also that it would be unwise to restrict in any way the development of improved or new methods or procedures by research workers because of standardization of this test method.

6. Apparatus

6.1 In general, the apparatus shall consist of the following equipment: a bell jar, power supply and multi-meter for voltage and current measurements, thermocouples and voltmeter or other readout, vacuum system, and specimen holders. A schematic of the test arrangement is shown in Fig. 1. Means must be provided for electrically heating the specimen, and instruments are required to measure the electrical power input to the specimen and the temperatures of the specimen and surrounding surface.

6.2 *Bell Jar*:

6.2.1 The bell jar may be either metal or glass with an inner surface that presents a blackbody environment to the specimen located near the center. This blackbody effect is achieved by providing a highly absorbing surface and by making the surface area much larger than the specimen surface area. The relationship between bell jar size and its required surface emittance is estimated from the following equation for the gray body shape factor for a surface completely enclosed by another surface:

$$F = \frac{1}{\frac{1}{\epsilon_1} + \frac{A_1}{A_2}\left(\frac{1}{\epsilon_2} - 1\right)} \tag{1}$$

For this test method to apply, the following condition must exist:

$$\frac{1}{\epsilon_1} >> \frac{A_1}{A_2}\left(\frac{1}{\epsilon_2} - 1\right) \tag{2}$$

This condition can be satisfied for all possible values of specimen emittance by an apparatus design in which A_1/A_2 has a value less than 0.01 and ϵ_2 has a value greater than 0.8. To ensure that the inner surface has an emittance greater than 0.8, metal and glass bell jars shall be coated with a black paint **(1)**.[5] It is permissible to leave small areas in the glass bell jars uncoated for visual monitoring of the specimen during a test. Metal bell jars can be provided with small-area glass view ports for sample observation.

6.2.2 The bell jar must be opaque to external high energy radiation sources (such as open furnaces, sunlight, and other emittance apparatuses) if they are in view of the specimen. Both the coated metal and coated glass bell jars meet this requirement.

[5] The boldface numbers in parentheses refer to the list of references at the end of this standard.

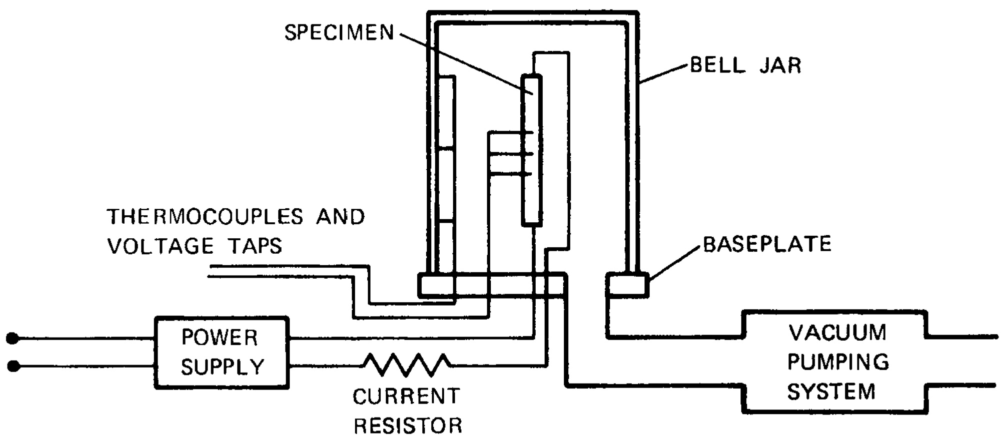


FIG. 1 System Arrangement

6.2.3 The need for bell jar cooling is determined by the lower-use temperature of the particular apparatus and by the maximum natural heat dissipation of the bell jar. A bell jar operating at room temperature (20°C) may be used for specimen temperatures down to about 120°C. At least a 100°C difference between the specimen and the bell jar is recommended to achieve the desired method accuracy. Therefore, for lower specimen temperatures, bell jar cooling is required. If the natural heat dissipation of the bell jar is not sufficient to maintain its temperature at the desired level for any other operating condition, auxiliary cooling of the bell jar is also required.

6.3 *Power Supply*—The power supply may be either ac or dc and is used to heat the test specimen electrically by making it a resistive part of the circuit. The true electrical power to the test section must be measured within a proven uncertainty of± 1 % or better.

6.4 *Thermocouples*, are used for measuring the surface temperature of the specimen. The thermocouple materials must have a melting point significantly above the highest test temperature of the specimen. To minimize temperature measurement errors due to wire conduction losses, the use of high-thermal conductivity materials such as copper should be avoided. The size of the thermocouple wire should be the minimum practical. Experience indicates that diameters less than 0.13 mm provide acceptable results.

6.4.1 The test section is defined by two thermocouples equally spaced from the specimen holders. A third thermocouple is located at the center of the specimen. Spot welding has been found to be the most acceptable method of attachment because it results in minimum disturbance of the specimen surface. Swaging and peening are alternative methods prescribed for specimens that do not permit spot welding.

6.4.2 The number of thermocouples used to measure the temperature of the absorbing surface shall be sufficient to provide a representative average. Four thermocouples have been found to be sufficient for the system shown in Fig. 1. Thermocouple locations include three on the bell jar and one on the baseplate.

6.4.3 The voltage drop in the measurement area of the specimen is measured by tapping to similar elements of each of the two thermocouples that bound the test section. A potentiometer, or equivalent instrument, having a sensitivity of 2μV or less is required for measuring the thermocouple emf's from which the test section temperatures are obtained.

6.4.4 Temperature sensors must be calibrated to within the uncertainty allowed by the apparatus design accuracy. For information concerning sensitivity and accuracy of thermocouples, see Table 1 of Tables E 230. For a comprehensive discussion on the use of thermocouples, see Ref **(2)**. For low temperature thermocouple reference tables, see Ref **(3)**.

6.5 *Vacuum System*—A vacuum system is required to reduce the pressure in the bell jar to 1.3 mPa or less to minimize convection and conduction through the residual gas. This effect is illustrated in Fig. 2, which shows the measured emittance of oxidized Inconel versus system pressure. This curve is based upon the ***assumption*** that all heat transfer from the specimen is by radiation. As pressure increases, gas conduction becomes important.

6.5.1 For the specified pressure level, a pumping system consisting of a diffusion or ion pump and mechanical pump is required. If backstreaming is a problem, cold trapping is required. The specifications of an existing system are included in Table 1 and photographs of a system are included in Fig. 3 and Fig. 4. This information is included as a guide to assist in the design of a facility and is not intended to be a rigid specification.

6.5.2 The specified pressure (1.3 mPa or less) must exist in the bell jar. If measured elsewhere in the pumping system, such as in the diffusion pump inlet, the pressure drop between the measuring location and the bell jar must be accounted for. The vacuum system should also be checked for gross leakage that could allow incoming gas to sweep over the specimen.

6.6 *Specimen Holders*, must be designed to allow for thermal expansion of the specimen without buckling. The lower specimen holder shown in Fig. 4 is designed to move up and down in its support to allow for thermal expansion.Holders should be positioned off-center within the bell jar to minimize normal reflections between the specimen and bell jar inner surface. Specimen holders require auxiliary cooling if end conduction from the specimen causes overheating.

6.7 *Micrometer Calipers*, or other means are needed to measure the dimensions (width and thickness) of the test

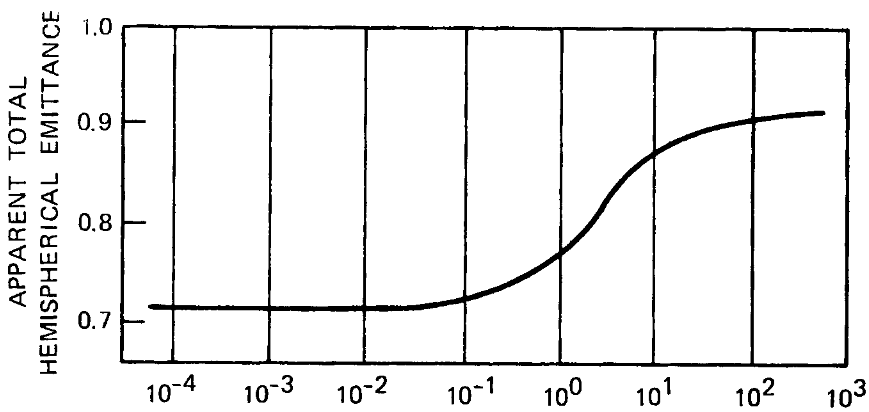


FIG. 2 Example of Effect of Air Pressure on Measured Emittance of Oxidized Inconel

TABLE 1 Specifications for the Emittance Test Facility Shown in Figs. 3 and 4

Vacuum system:
A manual vacuum coater system
Vacuum pumps consisting of an 0.8-m^3/s diffusion pump (100-mm inlet) backed by an 0.0023-m^3/s mechanical pump
A glass bell jar, 0.46 m in diameter by 0.91 m high with an implosion shield
Vacuum gaging, including two thermocouple-type roughing gages and an ionization gage
A specimen holder having a movable lower clamp to allow for thermal expansion
A liquid nitrogen cold trap
Power Supply:
Output voltage—0 to 16 V
Maximum current—100 A
Sample Temperature Range:
Maximum 20 to 1400°C
Sample Size:
Nominal—0.25 by 13 by 250 mm
Maximum length—500 mm
Power Measurement:
Current is determined by measurement of voltage across a precision-calibrated resistor (0 to 100 A)
Voltage is measured by a digital voltmeter.

specimen and the length between voltage taps and thermocouples at room temperature. The specimen dimensions (width and thickness) should be measured to the nearest 0.025 mm. The length between voltage taps should be measured to the nearest 0.5 mm. The length between thermocouples should also be measured to the nearest 0.5 mm.

6.8 All instruments shall be calibrated initially and recalibrated at reasonable intervals.

7. Hazards

7.1 Thin metallic specimens provide the possibility for cuts to the handler. Specimens should, therefore, be treated gently and with care.

7.2 Power leads to the apparatus should be well insulated and fused.

7.3 Power to the specimen should be cut off before dismantling has begun.

7.4 Normal safety precautions dictate that an implosion shield be provided if a glass bell jar is used. One example of a problem that can occur with a glass bell jar is the local thermal stress resulting from uneven heating of the bell jar.

8. Test Specimen

8.1 The specimen used for a test must be sufficiently uniform in surface to represent the sample material from which it is taken. Caution must be exercised to prevent contamination of the specimen surface from all sources, and especially from fingerprints.

8.2 The size of the test specimen must be compatible with the power supply and desired maximum test temperature. Fig. 5 shows acceptable overall test specimen dimensions for three materials in use with a 16-V, 100-A ac power supply. Specimens should be prepared so that edges are straight, smooth, and parallel. Edges should have the same surface condition as the rest of the specimen.

NOTE 1—Previous editions of Test Method C 835 described reference emittance specimens available from the National Institute of Standards and Technology (NIST). These specimens have been discontinued by the Standard Reference Materials Program at NIST.

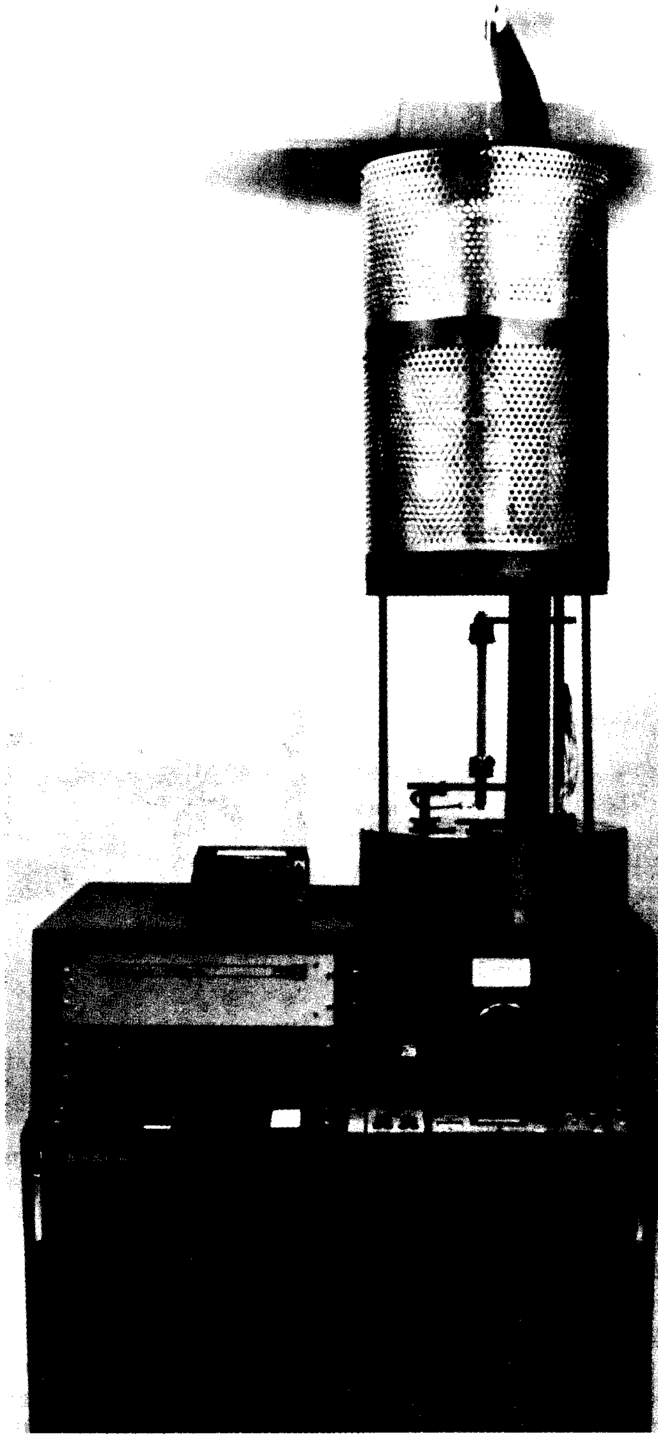


FIG. 3 Example of Vacuum Emittance Test Facility

8.3 Three thermocouples shall be fastened to the specimen over the test length as indicated in Fig. 5. A suitable test section length, *L*, compatible with the requirements of 8.2, has been found to be about 75 mm. The two wires that comprise a thermocouple should be spot-welded to the specimen surface separately. They can be attached either along a line normal to

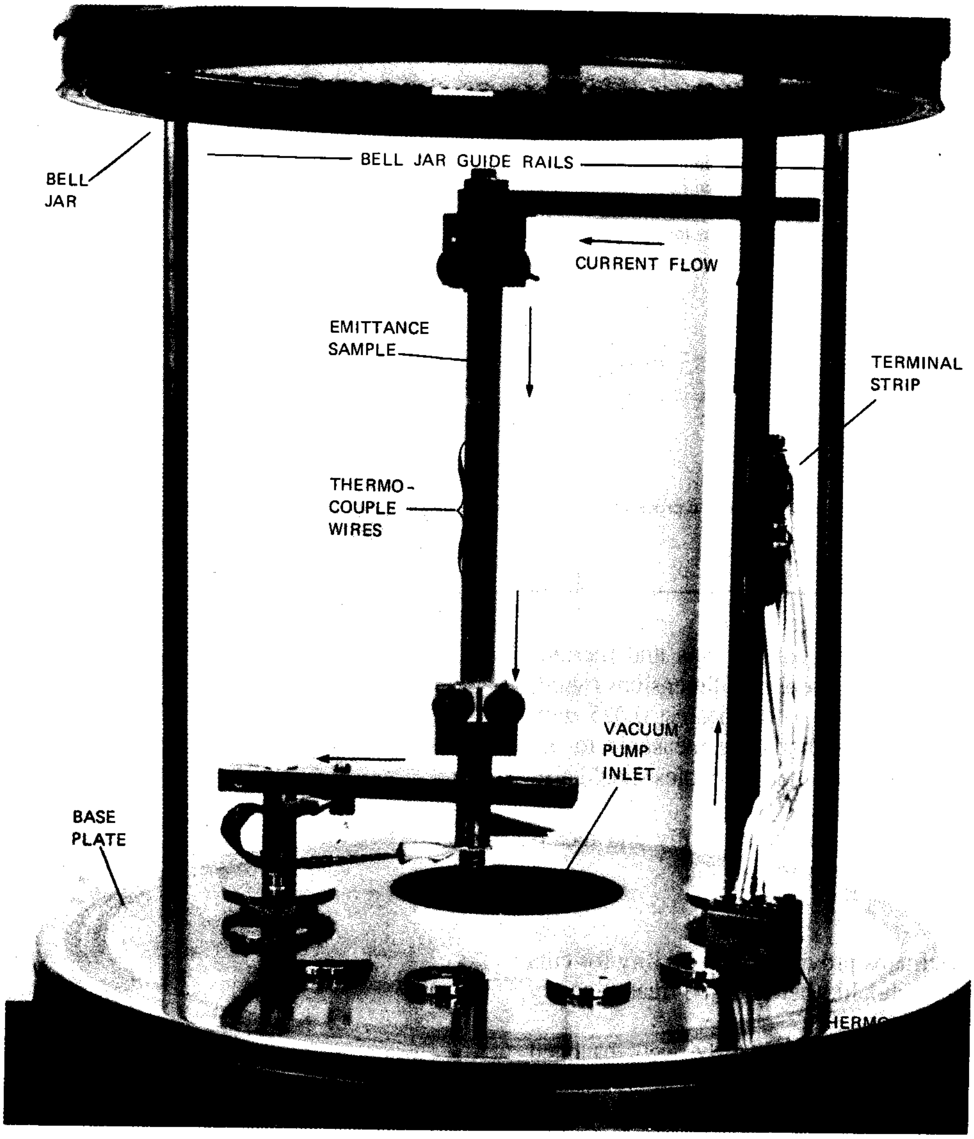


FIG. 4 Example of Emittance Sample in the Test Fixture

the specimen axis or displaced slightly (within 0.5 mm) along the axis. These two arrangements are illustrated in Fig. 6. The first arrangement allows a small displacement between the thermocouple wires and can be used with an ac power supply. Any ac pickup can easily be rejected when the thermocouple dc voltage output is measured. The second arrangement would position the thermocouple wires along an equipotential line and is required when a dc power supply is used. In this way, the specimen dc voltage drop will not influence the thermocouple output. Thermocouple wire alignment should be checked by reversing the power supply polarity at each reading. If the wires are properly aligned, the thermocouple output will not change.

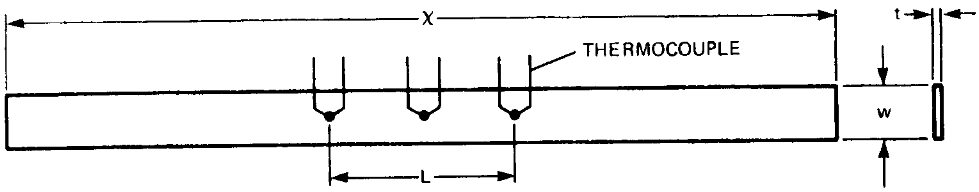
8.4 Similar elements of the two end thermocouples are used as voltage taps to measure the test section voltage drop.

8.5 The length of the test specimen between end connectors and end voltage taps must be sufficient to minimize conduction errors due to the heat sinks provided by the end connectors. The analytical results shown in Fig. 7 are included as guidelines to assist in the selection of test specimen and test section lengths. The four curves shown include combinations of emittance and thermal conductivity that cover a wide range of possible test specimen properties. These predictions are based upon a total conduction loss out of the test section equal to about 2.5 % of the power input to the test section.

8.5.1 The curve for aluminum illustrates that materials with high thermal conductivity and low emittance require the longest test specimen length and the shortest test section length. These effects are most pronounced for low test temperatures because the radiated power is at a minimum relative to the power conducted out of the test section.

8.5.2 If the original three thermocouples indicate a temperature gradient in the test section, additional thermocouples should be installed about 6 mm outside one or both ends of the test section. These extra thermocouples are used to better define the test section temperature profile.

8.5.3 Alternative means of minimizing end conduction errors are discussed in 12.4.



MATERIAL	t	w	L	X
INCONEL	0.25	13	75	250
STAINLESS STEEL	0.25	13	75	250
ALUMINUM	0.25	13	50	500

NOTE 1—All dimensions are in millimetres.

FIG. 5 Typical Test Specimen Dimensions

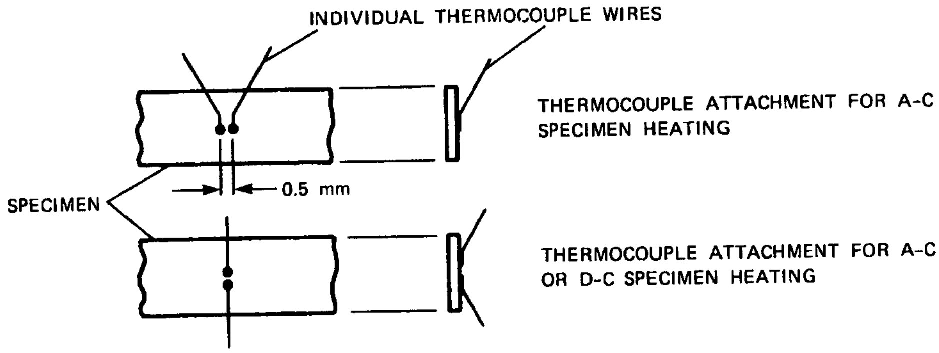


FIG. 6 Thermocouple Attachment

9. Verification

9.1 When sufficient apparatuses become available, they shall be verified by interlaboratory comparison testing on two specimens with emittances that span the expected range to be tested. If practical, the thermal conductivities of these specimens should also span the expected use range. Both specimens should be tested at several temperatures that span the use temperature of the test apparatus. Stable materials will need to be selected for verification purposes. The apparatus shall be considered successfully verified when measured emittance values from interlaboratory comparison testing can be duplicated to ±5 %.

10. Procedure

10.1 After connecting the electrical leads to the specimen and completing the hookup of thermocouples and voltage taps to available indicators or recorders, evacuate the bell jar to the desired pressure.

10.2 Heat the specimen electrically to the desired test temperature and allow power and temperature indications to stabilize.

10.3 After steady-state conditions have been attained, continue the test at the steady state with the necessary observations being made to determine the average surface temperature of the specimen, the average temperature of the bell jar inner surface, and the electrical energy input to the test section (central portion of test specimen). Continue the observations at intervals of not less than 5 min until three successive sets of observations give emittance values differing by not more than 1 %.

10.4 For some materials, the surface may change at high temperatures in a vacuum environment (**4**). Some materials oxidize in an imperfect vacuum and require purging the bell jar with nitrogen if this is a problem. To ensure that the surface has not changed during testing, the specimen shall be retested at one or more of the lower test temperatures after the maximum temperature has been tested. If the retested emittance value at a particular temperature has changed by more than 2 % of the original measured value, this test method shall not be applicable for the higher tested temperatures.

11. Calculations

11.1 Based on the assumption that the test specimen is a *small* radiating body surrounded by a large absorbing surface, the total hemispherical emittance of the specimen can be calculated as follows:

$$\epsilon = \frac{Q}{\sigma A_1 (T_1^{\ 4} - T_2^{\ 4})} \tag{3}$$

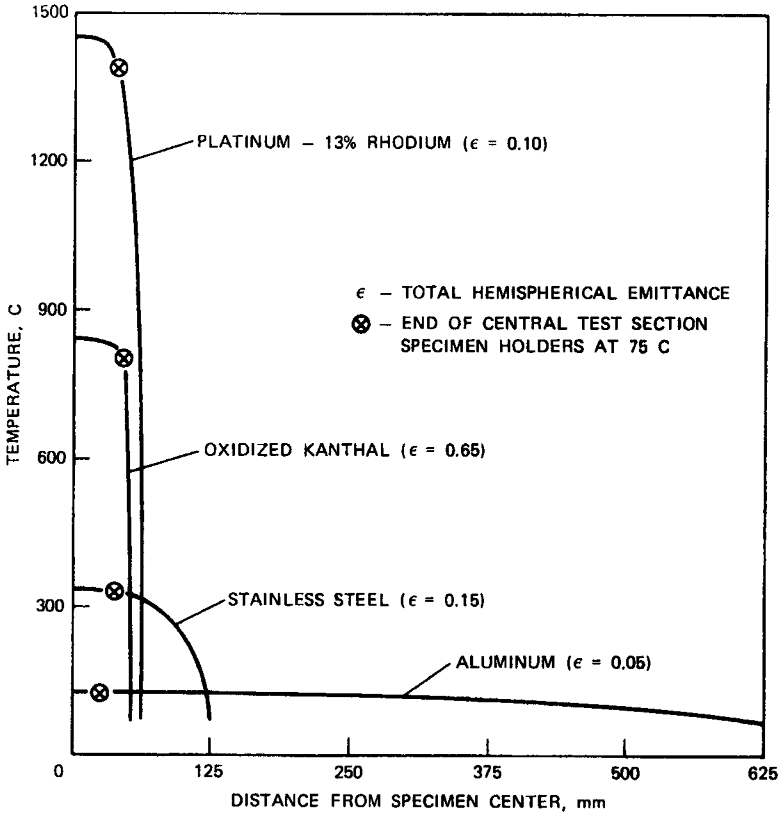


FIG. 7 Predictions of Specimen Temperature Distributions

where:

Q = heat generated in the specimen over the test specimen length, L, and

A_1 = total radiating surface of the specimen over the test section length, L, including edges that "see" the absorbing surface. This area is calculated from room temperature measurements of 6.7.

$$A_1 = 2L(w + t) \tag{4}$$

where L, w, and t are shown on Fig. 5.

11.1.1 Eq 3 is the result of simplifying assumptions, which are as follows:

11.1.1.1 The enclosure is a blackbody emitter at a uniform temperature and, as such, should absorb all incident radiant energy from the specimen (no reflection) and should emit radiant energy diffusely into the bell jar enclosure,

11.1.1.2 The absorption of the specimen for completely diffuse blackbody radiation at the temperature of the enclosure is equal to the total hemispherical emittance of the specimen at its temperature, and

11.1.1.3 There is no heat loss from the test section by convection or conduction, and therefore, all heat transfer to and from the test section is by radiant exchange only.

11.1.2 For most materials tested by the procedures described in this test method, these effects are small relative to the accuracy (±5 %) claimed for this test method. If certain effects cannot be neglected, corrections are required as described in the test procedure.

12. Sources of Experimental Error

12.1 This section discusses experimental error to aid in the design of a test facility and to assist in the analysis of the test results. As pointed out in 5.6, the use of this test method requires knowledge about the theory of heat transfer, temperature measurements, and general testing practices. Many problem areas can lead to significant experimental errors; some of these problems are: chamber wall reflections; chamber wall emittance changes with use; ac power measurements; conduction heat losses; thermocouple drift and measurement errors; specimen surface changes because of high temperatures and a vacuum environment; local perturbations of specimen surface temperature because of wire attachment; nonuniformities in coated specimens; and specimen temperature fluctuation due to ac heating. An evaluation of the potential sources of experimental error for both the specimen and apparatus is required to determine which items are significant. The significant items must be included in the calculation of emittance. Related references **(4, 5, 6)** on emittance testing are included to provide additional insight into many of the problem areas listed above. A few of the above items are discussed below as examples of potential sources of error.

12.2 *Chamber Wall Reflections*—Eq 3 is based upon the assumption that all radiation emitted from the specimen is absorbed by the bell jar inner surface. In reality, some of the radiation emitted by the specimen will be reflected from the bell jar surface back onto the specimen. To minimize this effect, a metal or glass bell jar inner surface can be coated to provide a highly absorbing surface.

12.2.1 An uncoated borosilicate glass bell jar may be used because it absorbs or transmits most of the incident infrared radiation. The "absorption" of the glass is greater than 0.80 and includes the effect of both absorption and transmission. As mentioned in 6.2, however, certain precautions are necessary when using an uncoated glass bell jar due to the possible transmission of radiant energy *into* the bell jar from very high temperature external sources.

12.2.2 The specimen should also be positioned off-center within the bell jar to minimize normal reflections from the bell jar inner surface. The ratio of specimen surface area to bell jar surface area should also be kept as small as practical. This ratio can be determined from the equation given in 6.2, but a guideline is a ratio of about 1/100 or less. Objects within the bell jar, such as power posts, should be positioned so that they "see" a minimum of the specimen surface.

12.3 *AC Power Measurements*—If the specimen is heated as part of an ac circuit, the true rms power must be measured. Power can be obtained by measuring the specimen voltage drop and current or by using a wattmeter. For the first method, a calibrated current resistor can be used in series with the test specimen. Since both the current resistor and test specimen can be considered to be pure resistive elements in an ac circuit, the voltage drop across each is in phase with the current through it. The instrument used to measure the test specimen and current resistor voltage drops must measure true rms voltage. Voltmeters are available that are based upon the heating effect of the applied waveform. In addition more recent types are available that compute rms voltage regardless of waveform.

12.4 *Conduction Heat Losses*—Power generated within the test specimen can be conducted out to the specimen holders on either end. The thermocouple wires will also conduct heat from the test section.

12.4.1 A significant temperature error can result from the heat conducted out through thermocouple leads. The thermocouple wire, acting as a fin, causes a temperature depression at the point of attachment. An analytical technique **(7)** is available for estimating this temperature error. Thermocouple wire size should be as small as practical to minimize these errors, and diameters less than 0.13 mm are recommended. The heat conducted out through the thermocouple leads is usually neglected.

12.4.2 For most specimens of reasonable length, it is necessary to correct for heat conducted to the specimen holders. For example, a type 304 stainless steel specimen that has a relatively low thermal conductivity with a 75-mm test section would require a small correction for end conduction. However, for a metal with high thermal conductivity such as aluminum, the end conduction can be significant and must be either eliminated or included in the calculation of total hemispherical emittance. A number of methods for reducing the axial temperature gradients in the test section are:

12.4.2.1 Making the ends of the test specimen long enough so that the entire temperature gradient is taken between the specimen holder and outer thermocouple on the test section. This may be impractical since specimen lengths beyond the limits of a standard bell jar would be required.

12.4.2.2 Providing for external heating of the specimen ends or specimen holders. These guard heaters would be controlled to minimize the temperature gradients out of the test section.

12.4.2.3 Attaching extension pieces, as shown in Fig. 8, to each end of the test specimen. The extension pieces would be type 304 stainless steel and would take most of the temperature gradient between the specimen and specimen holders. It is not possible to match exactly the specimen and end extensions so that the test section temperature gradients are eliminated over a wide range of temperatures. Consequently, small gradients will still exist in the test section and will require corrections based upon the measured temperatures. The advantages of this technique are short specimen length and no need for heaters and power supplies.

12.4.2.4 Notching the specimen outside the test section on either end reduces the cross-sectional area (Fig. 9). These reduced area sections result in high local heat generation and act as end heaters. The notches would have to be adjusted for each specimen and each temperature.

13. Report

13.1 Report the following information:

13.1.1 Name and any other identification of the material,

13.1.2 Details of any pretreatment of the specimen; for example, the time specimen was held at a specific temperature,

13.1.3 Thickness, width, distance between voltage taps and thermocouples of the specimen tested,

13.1.4 Arithmetic mean temperature of the test section, T_1,

13.1.5 Arithmetic mean temperature of the absorbing surface, T_2,

13.1.6 Voltage drop across test section and current through test section, or the test section power if a wattmeter was used,

13.1.7 Computed area of test section, A_1,

13.1.8 Computed total hemispherical emittance, ϵ_1.

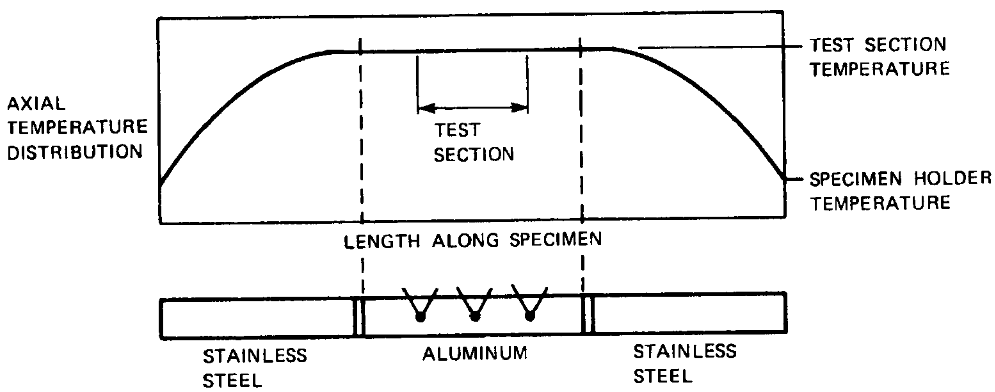


FIG. 8 Composite Specimen

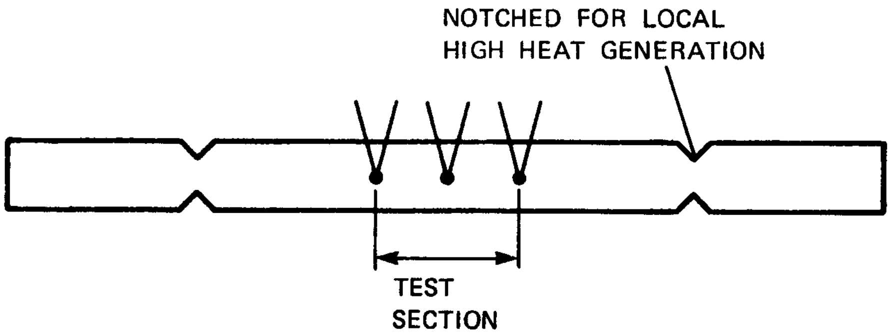


FIG. 9 Notched Specimen

14. Precision and Bias

14.1 *Precision*—The precision of this test method is indicated by the results of a limited test program conducted by two independent laboratories. While data sets from only two laboratories are available, the results can also be used to imply uncertainty to some degree. As the number of participating laboratories increases, the precision and bias estimates improve. The laboratory 1 tests were conducted during the development of this test method, while the laboratory 2 tests were conducted prior to this work. The test program did not strictly conform to Practice E 691. The results are reported in Table 2. Laboratory 1 used the method which was later adopted as Test Method C 835. Laboratory 2 used a similar method, except for the measurement of the test section temperature. Laboratory 2 employed an infrared pyrometer to measure the test section temperature. These are the only known interlaboratory comparison data available.

14.1.1 The uncertainty of this test method has been estimated using the statistical approach for random errors described in Ref **(7)**. The percent error in the computed emittance, $e_{\epsilon 1}$, results from the propagation of the measurement errors and is estimated as follows:

$$e_{\epsilon 1} = \sqrt{e_Q^{\ 2} + e_{A1}^{\ 2} + e^2(T_1^{\ 4} - T_2^{\ 4})} \tag{5}$$

Based on the analysis, the uncertainty of this test method is ±5 %. Representative results from the error analysis are presented in Table 3 for two specimens, each at two temperatures. Results given in Ref **(6)** for similar equipment yield a determinate error of ±2.7 % and a reported repeatability of less than ±2 %.

14.1.2 The heat dissipated from the test section by thermal radiation, Q, is computed based on the heat generated in the test section, the heat flow by axial conduction at the ends of the test section, and the heat loss through the thermocouple wires. This test method requires that the heat generated in the test section be measured to within ±1 %. Accordingly, the analysis of the error in the dissipated heat includes these three sources of error.

14.1.3 The error in A_1 is based on the error in the measurement of the individual test section dimensions. Thermal expansion, if important, should be accounted for in this test method or in the accuracy calculations. This is the only significant error identified.

14.1.4 The error in $(T_1^{\ 4} - T_2^{\ 4})$ is based on the errors in the individual temperature measurements. The analyses of the errors in T_1 and T_2 consider sources such as voltmeter accuracy, error in the thermocouple reference temperature, error in the thermocouple wires, and error in an analytically determined correction term which accounts for the temperature depression at the junction of the thermocouple wires on the specimen.

14.2 *Bias*—No information can be presented on the bias of the procedure in Test Method C 835 for measuring total hemispherical emittance, because no material having an accepted reference value is available.

TABLE 2 Results from Interlaboratory Emittance Testing in Support of Test Method C 835

T_1, K	ϵ_1 Laboratory 1	ϵ_1 Laboratory 2	Difference in Measured ϵ_1, %
	Specimen 1		
422	0.722	0.747	3.46
534	0.756	0.792	4.76
757	0.791	0.829	4.80
868	0.801	0.837	4.49
1040	0.825	0.860	4.24
	Specimen 2		
421	0.727	0.771	6.05
535	0.761	0.814	6.96
758	0.798	0.845	5.89
867	0.812	0.854	5.17
1040	0.840	0.860	5.24

15. Keywords

15.1 absorption; blackbody; emittance; hemispherical; radiation

TABLE 3 Representative Results from Error Analysis of Test Method C 835 Emittance Test Method

	Relatively Low ϵ_1(3003H16 Bright Finish Aluminum)		Relatively High ϵ_1(Painted 304 Stainless Steel)	
ϵ_1	0.0434	0.0560	0.89	0.92
T_1, T_2, K	420	670	424	816
$e_{\epsilon 1}$, ±%	4.35	2.30	4.89	2.67
$e(T_1^{\ 4} - T_2^{\ 4})$, ± %	3.91	1.74	4.76	2.42
e_{A1}, ± %	1.12	1.12	1.10	1.10
e_Q, ± %	1.55	1.01	0.277	0.213

REFERENCES

(1) Recommended coatings include: (a) Energy Control Products Projects 3M-SCS-2200 Experimental Solar Absorber Coating; St. Paul, MN 55144 or (b) PTI PT 404A Hi-Heat Coating (1100°C), Product Techniques, Inc., 1153 N. Stanford Avenue, Los Angeles, CA.

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