NATIONAL BUREAU OF STANDARDS REPORT

1454

COMBUSTIBILITY TESTS
OF
47 ASTM MATERIAL SAMPLES

by

Nicholas P. Setchkin

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ABSTRACT

Tests of 47 specimens of solid materials as requested by the advisory group to Subcommittee V, ASTM Committee E-5 on Fire Tests of Materials and Constructions were made at the National Bureau of Standards for the purpose of evaluating a technique for determining the combustibility classifications of solid materials. Results of these tests indicate that by using the technique proposed for adoption by ASTM, the specimens, except for a few, could be readily classified as combustible or incombustible. The results for those few were not conclusive and seem to require further definition of the procedure and method of classification.

I. INTRODUCTION

The advisory group of Subcommittee V of ASTM E-5 has proposed the use of a small furnace type of combustibility tester to evaluate the fire-hazard properties of various solid materials. This report presents the results of tests made with this device on each of 47 solid materials which are being tested independently by seven laboratories.

II. OBJECT

The objective of the tests was to classify each of the 47 solid materials as to their combustibility characteristics for the purpose of comparing experimental results with those obtained by workers in other laboratories.

III. TEST APPARATUS

The National Bureau of Standards ignition apparatus for solids, figure 1, was used for these tests.

a. Construction

The apparatus consists of a small cylindrical electrically heated furnace. A refractory tube 4 in. inside diameter by 8 3/4 in. long forms the cavity. A second refractory tube 3 in. inside diameter by 8 3/4 in. long is supported within to provide the combustion chamber of the furnace. The incoming air is preheated to furnace temperature in the annular space between the two tubes. It enters the bottom of the combustion chamber, rises around the specimen, and leaves through an opening in the furnace cover. This opening is also used for observation of the behavior of the specimen within the furnace. For certain tests, a gas pilot flame burns above the opening in the furnace cover. The plug at the bottom of the furnace facilitates removal of residue collecting during the tests.

b. Electric Power Supply

The furnace was normally operated from the laboratory 120-volt power supply lines through a variable ratio autotransformer. In some tests involving high air velocities, it was necessary to use up to 220 volts. The auto-transformer was adjusted to provide an output of 60 volts for the first five minutes after which it was gradually increased during the next 30 minutes to about 90 volts, corresponding to a power consumption of about 500 watts. The power consumption of the furnace varied with the rate of air flow and the operating temperature. The maximum safe operating temperature of the furnace is 1000° C.

c. Air and Gas Supplies

The compressed air was reduced from the line pressure of 125 lb/in.^{2} to 30 lb/in.^{2} by means of a pressure regulator. A needle valve and dry gas meter were used to control and measure the air flow rate. Most tests were run with an air velocity past the specimen of about 7 to 15 ft/min under the temperature conditions involved. The rate of flow required depended upon the material under test and the rate of its decomposition reaction.

The velocities corresponded to volumetric rates of air flow at 70° F of from about 0.09 to 0.17 ft^3/min for the particular apparatus used during these tests. Air velocity has been reported in the tables in preference to volumetric flow rate because it is believed that the velocity of the air past the specimen is the critical variable. For a given volumetric flow, this velocity will depend upon the dimensions of the furnace and specimen. The rate at which air is supplied must be a compromise between the need of oxygen for the reaction leading to ignition and the need for regulating heat losses from the specimen resulting from a high rate of air flow.

Variations of air velocity past the specimen are not likely to cause difficulty in the classification of specimens which consist largely of combustible material. However, for materials having very low combustible content the use of high air velocities past the specimen may obscure the flaming or self-heating which would otherwise be noted. High air velocities also have the disadvantage of requiring excessively high rate of power consumption within the furnace as indicated on chart 20.

The gas pilot flame, when used, was adjusted to provide a flame about 3/4 in. long. However, this pilot was not used during most of the tests because the heat from the furnace wall provided an adequate ignition source.

d. Thermocouples

Thermocouples were mounted as shown in figure 1. Thermocouple T_1 followed closely the heating coil temperatures; T_2 indicated air temperatures below the specimen; T_4 served as an indication of surface temperature of the specimen while T_3 was used in measuring temperature within the specimen.

During most of the tests, thermocouples formed from No. 26 B&S gage chromel and alumel wires were used because of their quick response. In some tests conducted with treated wood it was necessary to use thermocouples made from No. 18 B&S gage wires because of excessive corrosion of the finer wires. Calibration data for these wires are presented in table 1.

Table 1. Calibration of thermocouples of Nos. 18 and 26 B&S gage chromel and alumel wires

Temperature	Electromotive force developed by	
	No. 18 gage wire	No. 26 gage wire
°F	mv	mv
200	3.80	3.82
400	8.30	8.27
600	12.85	12.78
800	17.55	17.39
1000	22.26	22.15
1200	27.05	26.90
1400	31.70	31.65
1600	36.25	36.20
1800	40.63	40.68
2000	44.95	45.00

e. Size of Specimen

The size of the specimen tested varied with the type of material but in most cases was cut 1.5 in. wide, 2 in. long, and not over 1.5 in. thick. For thin sheet materials, a number of sheets were assembled to provide a thickness of not less than 1/4 inch. Loose materials, such as mineral wool, were either made into a bundle 1.5 x 1 x 2 in. or were inserted in a wire screen container having these dimensions.

IV. TEST PROCEDURE

After warming up the furnace and adjusting the rate of air flow to that required for the test, the furnace temperature was adjusted to 1383 ±5° F as indicated by the thermocouple T_2. The temperature of the heating coils was observed with the thermocouple T_1. A specimen with attached thermocouples T_3 and T_4 was fastened to a wire and lowered to the middle of the furnace tube. Observations were then made of the behavior of the specimen with particular reference to flaming or glowing. The time-temperature data were also recorded for both the surface and interior of the specimen. During these observations, the temperature of the furnace coils at T_1 was maintained constant regardless of changes of air temperature at T_2.

Self-heating of the specimen was taken as another indication of combustibility and was observed during the tests by a rise of the interior temperature of the specimen above the initial temperature of the air in the furnace.

The rate of rise of temperatures at the surface and in the interior of the specimen at the beginning of the test were not considered of great significance since these vary considerably with test conditions such as air-supply rate, sample size, and locations of the thermocouples in the specimen with respect to the point of ignition or region of maximum self-heating.

The duration of the test varied with the characteristics of the material tested. Definitely combustible materials usually required only 3 to 5 minutes for classification. Incombustible materials, on the other hand, usually required longer exposure periods to permit observation of temperature changes within the specimen. In most cases, the test period did not exceed 15 to 20 minutes.

V. TEST RESULTS

The results obtained from tests on the samples of the 47 materials are presented in tables 2, 3, and 4. Time-temperature data, together with some notes on observations of the specimens during test, are presented in the charts included in this report.

Table 2 lists materials which can definitely be classified as combustible, as evidenced by flame, self-sustained glow, and/or pronounced self-heating.

TABLE 2. DEFINITELY COMBUSTIBLE MATERIALS

CODE	CHART	MATERIAL	EVIDENCE: FLAME OR GLOW: LENGTH	EVIDENCE: FLAME OR GLOW: DURATION		EVIDENCE: SELF-HEATING: ON SURFACE	EVIDENCE: SELF-HEATING: IN CENTER	AIR VELOCITY	REMARKS
NO.	NO.		IN.	MIN	SEC	°F	°F	FT/MIN	
I-1	1	ASPHALT CANVAS (2 SHEETS)	3	0	25	75	235	15	VERY DENSE SMOKE
I-1	1	DO (1 SHEET)	2	0	20	——	267	15	DO
I-1	1	DO DO	2	0	25	——	207	15	DO
I-2	1	ASPHALT PAPER (2 SHEETS)	4	1	45	97	145	15	DO
I-2	1	DO (1 SHEET)	2	0	55	157	——	15	DO
I-3	2	DO (2 SHEETS)	6	1	45	217	——	15	DO
I-3	2	DO (1 SHEET)	3	0	55	117	——	15	DO
I-4	2	RED ASPHALT BOARD	4	1	45	160	——	15	DO
I-5	2	ASPHALT PAPER (2 SHEETS)	6	0	55	167	——	15	DO
I-6	3	DO DO	8	2	40	240	——	15	DO
I-7	3	1/2-INCH ASPHALT BOARD	8	3	20	297	237	12	VIOLENT BURNING
I-8	4	1/16-IN. CARDBOARD (2 SHEETS)	5	0	25	257	——	15	DENSE SMOKE
I-13	6	ASBESTOS ASPHALT (2 SHEETS)	~2	1	07	272	——	15	GLOW, LIGHT SMOKE
II-1	6	DOUGLAS FIR (TREATED)	~2 BLUE	2	00	387	287	18	INTENSE GLOW
II-2	7	DO DO	~2	3	45	270	287	18	DO
II-3	7	DO DO	~2	4	50	387	247	18	DO
II-3	7	DO DO	2	7	00	92	157	130	INTENSE BURNING
VI-1	9	EAGLE INSULATION BATT	FLASH	0	25	——	167	12	DULL GLOW
VI-2	10	ROCK WOOL (LOOSE)	FL&GL	0	20	——	237	12	HELD BY WIRE
VI-2	10	DO DO	FL&GL	0	30	——	297	13	HELD IN WIRE SCREEN
VI-2	10	DO DO	NO FLAME			——	137	143	DO
IX-1	12	GLASS WOOL PAD (HIGH DENSITY)	~2	0	25	——	175	8	DULL GLOW
IX-4	13	DO DO	2	3	30	67	157	10	DO
IX-5	13	DO DO	2	1	15	202	67	10	DO
XI-1	14	DOUGLAS FIR	6	5	53	437	317	10	BURNING GAS BELOW SPECIMEN
XI-2	14	YELLOW PINE	6	6	30	407	387	8 & 11	DO
XI-3	15	POPLAR	8	5	20	525	372	16 & 8	DO
XI-4	15	DOUGLAS FIR (TREATED)	2	6	10	342	257	10	DO
XI-5	16	DO DO	5	10	00	377	292	10	DO
XIV-1	17	OAK DO	~2	12	30	432	357	9	DO
XIV-2	18	POPLAR DO	~2	12	00	——	(147)	10	FALL TO BOTTOM
XIV-2	18	DO DO (½ SIZE)	~2	7	00	247	267	10	DO
XIV-3	18	BIRCH DO	~2	12	30	277	347	10	BURNING GAS BELOW SPECIMEN

Table 3 presents a tabulation of materials which are definitely classified as incombustible by the test. These samples produced no flame or evidence of self-heating.

TABLE 3. DEFINITELY INCOMBUSTIBLE MATERIALS

CODE	CHART	MATERIAL	EVIDENCE		AIR VELOCITY	FUSION		
			FLAME OR GLOW	SELF-HEATING		TEMPERATURE	TIME	
NO.	NO.				FT/MIN	°F	MIN	SEC
I-9	4	1/8-IN. ASBESTOS CEMENT BOARD	NONE	NONE	15	—	—	
I-10	4	1/8-IN. ASBESTOS CEMENT SHINGLE	DO	DO	15	—	—	
I-11	5	1/4-IN. ASBESTOS CEMENT PLATE	DO	DO	15	—	—	
I-12	5	1/4-IN. DO	DO	DO	15	—	—	
III-2	8	3/4-IN. KAYLO MAGNESIUM BLOCK	DO	DO	10	—	—	
IV-1	8	5/8-IN. DO	DO	DO	10	—	—	
VII-1	10	ROCK WOOL (LOOSE)	DO	DO	12	—	—	
VII-2	10	ROCK WOOL BATT	DO	DO	12	—	—	
VIII-1	11	ALUMINUM ALLOY SHEET	—	DO	8	1300	4	20
VIII-2	11	DO	—	DO	8	1265	6	00
VIII-3	11	DO	—	DO	8	1300	3	40
VIII-4	11	DO	—	DO	8	1310	4	30
VIII-5	12	DO	—	DO	8	1292	4	00
VIII-6	12	DO	—	DO	8	1270	4	20
IX-3	13	GLASS WOOL PAD	NONE	DO	10	—	—	
IX-5	13	DO	DO	DO	130	—	—	
X-1	13	MAGNESIUM ALLOY BLOCK	DO	DO	10	—	—	

Table 4 lists materials of minor combustible content. These materials exhibited brief flaming and little or no self-heating. They usually consisted of incombustible material with either a covering or admixture of a small amount of combustible material. The final classification of materials of this group should be made in accordance with adopted definition of combustible and incombustible materials.

TABLE 4. MATERIALS OF UNCERTAIN CLASSIFICATION

CODE	CHART	MATERIAL	EVIDENCE: FLAME OR GLOW			EVIDENCE: SELF-HEATING		AIR VELOCITY
			INTENSITY	DURATION		ON SURFACE	IN CENTER	
NO.	NO.		IN.	MIN	SEC	°F	°F	FT/MIN
III-1	8	ASBESTOS PAPER (3 SHEETS)	FLASH	0	05	NONE	NONE	10
V-1	9	PAINTED STEEL PLATE	~ 2	0	20	DO	DO	12
VI-1	9	EAGLE INSULATION BATT	FLASH	0	10	DO	DO	128
IX-2	12	GLASS WOOL PAD	FLASH	0	10	DO	DO	10
XII-1	16	1/2-IN. PLASTERBOARD	2	1	20	DO	DO	10
XII-2	16	1/2-IN. PLASTERBOARD	2	1	25	DO	DO	10
XIII-1	17	1/2-IN. PLASTERBOARD	3	1	25	——	35	10

VI. DISCUSSION

a. Evidence of Combustibility

The combustibility of materials with respect to their fire hazards was indicated during the tests by flame, sustained glow, and/or self-heating.

The flame was characterized by color, intensity, and duration. The color of the flame, orange, blue, and light purple (clear), seemed to indicate about the same degree of fire hazard. However, the intensity combined with duration of flaming may indicate different degrees of fire hazard. Intense flames or those of long duration naturally represent hazards of higher degree than the weak ones or those of only a few seconds duration. The latter types of flame were observed in the tests with asbestos paper (sample III-1)[1], glass-wool pad (sample IX-2), painted-steel plates, and other materials of minor combustible content, listed in table 4 as "uncertain".

[1] Numerals in parenthesis indicate the Code numbers in tables.

Theoretically, the materials of the "uncertain" group are also combustible. However, from a practical point of view, this classification should probably be modified to "minor combustible content" if the effect of the combustible component can be considered negligible in comparison with the large proportion of incombustible basic material.

Glow and self-heating may be considered as evidences of different degrees of the same ignition characteristic. Temperature conditions in the specimen in which a bright red or yellow color was visible, that is 1550° F and above, were produced by the process of self-heating. They are commonly referred to as "glow" whereas, temperature conditions below 1550° F, as indicated by the thermocouple measurements, have been called "self-heating". Slow self-sustaining combustion is distinguished from both rapid combustion with flaming and self-heating (which may include glow) sustained only by the high temperature of the surroundings. The glow which continues after the material has been removed from the furnace is defined as "sustained glow" and shows definite evidence of combustibility.

Self-heating without sustained glow or flaming is not necessarily evidence of combustibility of the material as a whole. However, self-heating of materials to high temperatures would present a definite fire hazard to materials of low-ignition temperatures stored nearby or in contact with the self-heating material. For example, asbestos insulation containing over 5 percent of combustible components when heated to 500° F (260° C) has further self-heated to 1110° F (600° C). This would almost certainly cause the ignition of paper, wood, or other low-ignition temperature materials stored nearby. Therefore, evidence of appreciable self-heating must be considered as a characteristic of combustible materials.

The extent of self-heating that should be permitted before a material is reclassified from minor combustible content to combustible is uncertain. U. S. Coast Guard Specification W164.009, which uses a similar test method to the one mentioned here, allows a temperature rise of 18° F (10° C). Experience with materials being evaluated for compliance with this specification indicates that this is a very conservative limit and that a temperature rise of 54° F (30° C) would be more practical. Previous experiments[2] involving the fire hazard of asbestos chimney insulations, acoustical tile, and other materials have shown that the carbon content of the material in question was well correlated with the combustibility characteristics. In order to establish justifiable limits for the self-heating,

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[2] N. P. Setchkin and S. H. Ingberg, Test Criterion for an Incombustible Material, ASTM Proc. V. 45, pp. 866-877 (1945).

flashes, and short flaming, it seems desirable to conduct large-scale experiments with materials of the uncertain group or those of minor combustible content.

b. Time-Temperature Curves

The rising temperature in the specimen was observed at convenient times and recorded in millivolts on cross-section paper; the paper was also graduated in degrees F or C. This procedure was found to be more suitable than recording in a table at specified intervals because the trend of the time-temperature curves and accidental errors can be noticed at once and correctly judged in respect to other data. Moreover, any kind of observation can be recorded on the same sheet in respect to observed time.

The time-temperature curves, obtained with the thermocouples placed on the surface and in the mass of specimens, have only relative value for the indication of maximum self-heating occurring on the surface or within the material. The shape and relative position of the curves, with respect to observed time, vary with location of the thermocouples, air velocity, and distance from the locus of ignition. Therefore, these curves should not be treated as precise characteristics of the material.

The magnitude of the self-heating should always be measured as an increase above the temperature indicated by the air thermocouple T_2 prior to inserting the specimen within the furnace, but not above the actually observed air temperature at the time of test. The reading of thermocouple T_2 was often affected by radiation from the specimen or combustion of gases below.

c. Effect of Air Velocity

Changes in air velocity around the specimen produce various effects depending upon the material tested. The intensity of the flaming of highly combustible materials ordinarily increases with the increase of air velocity (sample II-3), but for materials of lower combustibility this flaming may be reduced so much that a material of an uncertain group can be rated as combustible with low air velocity and as incombustible with high air velocity (samples VI-1, IX-5). Moreover, the magnitude of the self-heating of the material decreases with increased air velocity as shown in chart 7 (sample II-3), chart 9 (sample VI-1), chart 10 (sample VI-2) and chart 13 (sample IX-5).

The supplemental tests conducted with mineral wool and glass wool of high densities (samples A and B, chart 19) also indicated different effects of high and low air velocities. The combustibility of mineral wool (sample A) in air of 12.8-ft/min velocity was indicated by a bright orange flame during a 3-minute period, and in air of 128-ft/min velocity by a short blue flame for only 40 seconds, with substantially the same self-heating of the material. The behavior of the glass wool sample B with velocities of 13.7 and 133 ft/min were about the same. A short flame was observed for 40 and 30 seconds, respectively, but self-heating of the material was not observed.

d. Size of Specimen

The most favorable size of specimens for this furnace appears to be about 1 1/2 in. wide, 2 in. long, and from 1/2 to 1 in. thick. Greater thicknesses would tend to restrict the free passage of air between the furnace wall and the specimen, thus making observation of the flame difficult. Very thin sheets or plates of material also are not favorable for observation of the self-heating of materials. Therefore, a few sheets should be assembled into one specimen in order to increase the total thickness of a test specimen to not less than 1/4 inch.

e. Electric Current Supply

A current of 120- or 220-volt potential was used for heating the apparatus, depending upon selected air flow. The current input and temperature of the heating coils was increased rapidly with the air flow as shown on chart 20. The maximum temperature for the refractory tube and coil protection was not allowed to exceed 1832° F (1000° C). Therefore, for long service of the apparatus and its economical operation, it would be advisable to keep the temperature below this limit.

VII. CONCLUSION AND RECOMMENDATIONS

The above test results and discussion indicate that the ignition and combustion characteristics of materials are usually well defined by the method tentatively adopted by Subcommittee V for the classification of combustible and incombustible materials. The uncertainty of classification for a few materials can probably be resolved by further refinement and definition of the test conditions.

One test condition which should be modified for uniformity of results is the rate of air flow. This rate should be so adjusted that air velocity around the specimen (about 7 to 15 ft/min) would be favorable to the development of ignition reaction in the material subjected to test and at the same time avoid excessive heat losses. A second item is related to procedure in the observation of major evidences of ignition that involve the intensity and duration of flaming or sustained glow. The attention of an observer should not be diverted to the observation of the initial portions of the time-temperature curves, which have no practical value until they approach the maximum. The main significance of the time-temperature curve is that it indicates the maximum self-heating of the specimen or that no self-heating has occurred.

Difficulties in defining a few materials with properties placing them in the boundary zone between combustible and incombustible types were to be expected, and complications arose as to their classification particularly in view of practical applications. Therefore, the fire-hazard characteristics of materials of uncertain classification should be determined in large-scale tests, and the results correlated with the above data and the limited percentage of combustible components components permitted in the material.

On the basis of already available data, the following recommendations are suggested:

> The limit for combustible components in incombustible materials should not exceed 3 percent. Duration of flame at 1383° F should not be more than 30 seconds. Self-heating should not exceed 54° F (30° C) above the initial temperature in the apparatus.

THE NATIONAL BUREAU OF STANDARDS

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