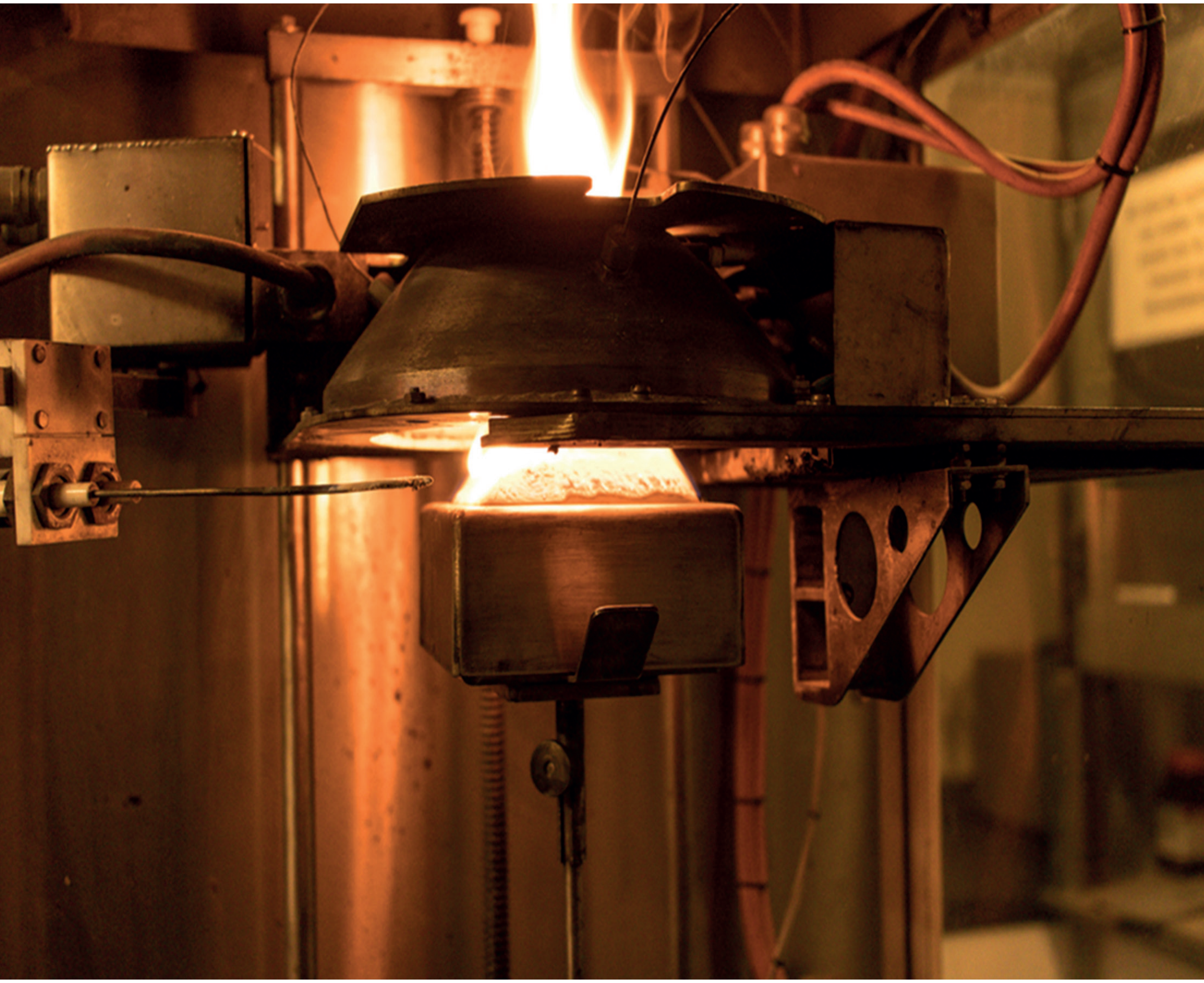

CONE CALORIMETER TESTING

HEAT AND VISIBLE SMOKE RELEASE RATE TESTING

ABSTRACT

Heat release is the primary cause of fire spread and growth; hence, it represents a key measurement parameter to assess the flammability of materials and products and their consequent fire risk.

The cone calorimeter test analyzes the behavior of products and materials when exposed to a radiant heat insult. The method simultaneously determines the fire response and the production of smoke of materials in a laboratory setting, which helps to make real-world fire predictions.

The purpose of this article is to discuss cone calorimetry and the relationship to fire contribution. The first section of the document provides introductory information on the cone calorimeter and the principle behind oxygen consumption calorimetry. It also discusses the ability of the cone calorimeter to be used as an effective tool to predict full-scale product performance.

This is followed by an outline of the test apparatus, including details of materials applicable to the test, and specimen requirements. The advantages of this test method over other flammability tests are also illustrated.

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BACKGROUND

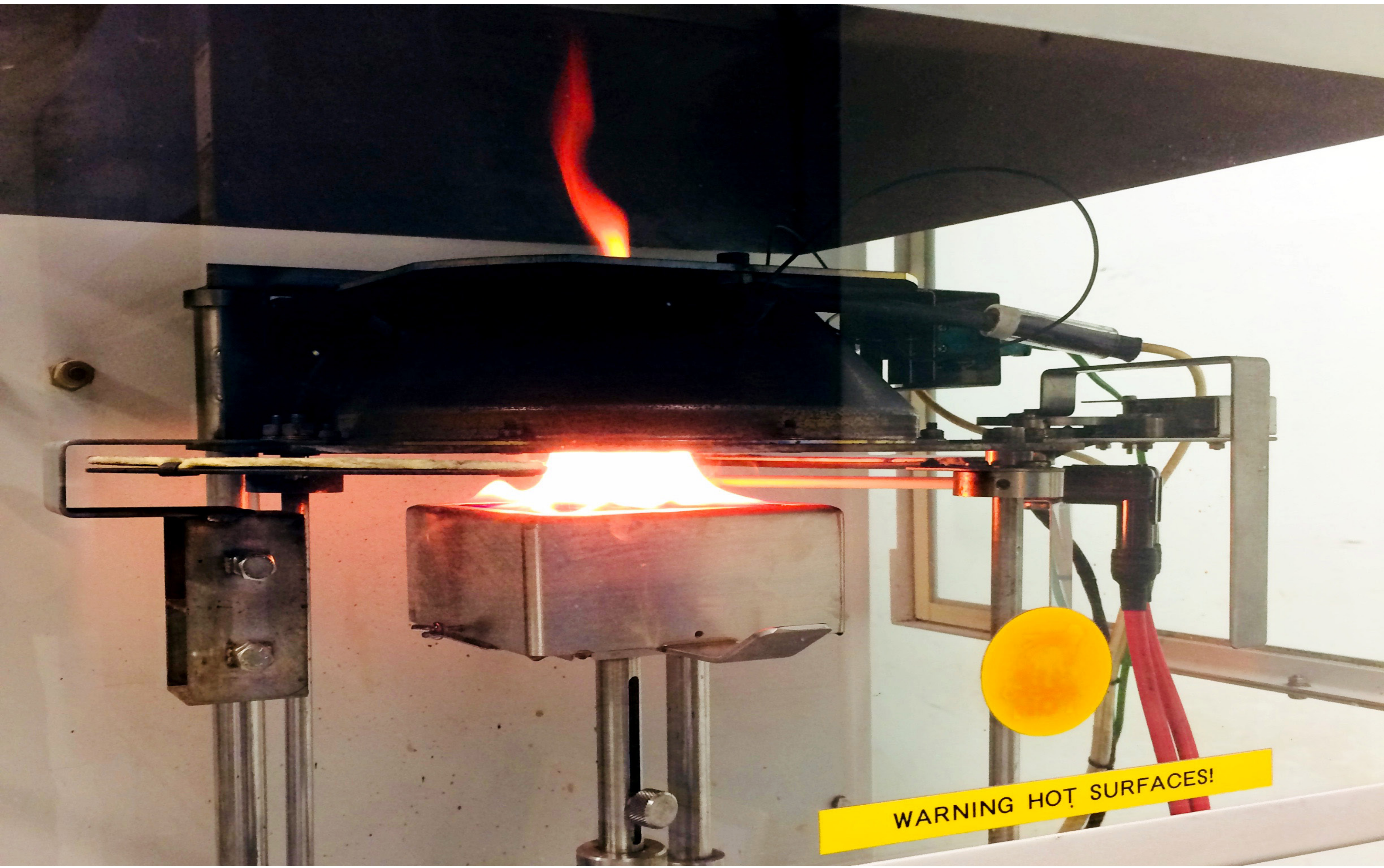
Reaction-to-fire (R2F) testing analyzes how a material or product responds to a controlled fire challenge. Measurements can include how fast the material ignites, how much and how quickly heat is emitted, how much mass is lost, and how much smoke is produced.

The rate of heat release is considered to be the most significant predictor of a potential fire hazard, and the cone calorimeter is the most valuable bench-scale instrument in fire testing to quantitatively evaluate the relative risk that different materials pose.

For this reason, the cone calorimeter is largely used when testing products that are under development. It can be utilized as a quality control tool and as a means to cross-correlate and predict material performance in other tests.

A comprehensive range of data can be collected from a cone calorimeter test, and that data can be assessed to study and compare materials under similar combustion conditions. In many cases, established threshold criteria are assigned by regulatory authorities, with the goal of limiting the potential of materials to contribute to real-life fires, protecting people from fire hazards and maintaining a safe environment.

The cone calorimeter test apparatus has been adopted by the International Organization for Standardization as its bench-scale method for measuring heat release rate (ISO 5560). The same equipment is also referenced by the American Society for Testing and Materials as ASTM E1354 and by Underwriters' Laboratories of Canada as CAN/ULC-S135.



CONE CALORIMETER TESTING

The heat release rate is a critical parameter to characterize a fire. In particular, the timing and magnitude of peak rate of heat release, and the short term average rates of heat release, are the most important factors in predicting fire growth rate.

Different methods have been developed to determine these factors. The cone calorimeter is currently the most advanced test method.

A cone calorimeter is primarily used as a standard test and as a research tool to understand the burning characteristics of materials and products under a range of conditions. In a laboratory setting, it makes it possible to evaluate the propensity of the materials under test to ignite, contribute to heat, produce smoke, or lose mass. Combinations of the measured parameters can also be assessed mathematically, to generate other critical predictors of material potential.

Additional advantages to cone calorimeter testing are the ability to determine non-combustibility of materials and their critical heat flux. In some jurisdictions, in addition to standard test protocols, cone calorimeter data can be used for materials that are unsuitable for other types of non-combustibility testing (e.g. ASTM E136 or CAN/ULC-S114).

The cone calorimeter can also be used to determine the critical heat flux of a material. By varying the intensity of the radiant heat flux imposed on a material, that heat flux can be narrowed to define when a material ignites. This determines the actual heat flux below which a material would not be expected to ignite, within a chosen test period. This type of testing can play an important role in material selection for critical applications.

OXYGEN CONSUMPTION

The principle on which measurements of heat release are based in a cone calorimeter is oxygen consumption during combustion, also known as oxygen depletion. The heat released from combustible materials, including most natural and synthetic plastics, rubbers and textiles has been shown to be proportional to the amount of oxygen required for combustion. Approximately 13.1 x 103 kJ of heat are released per 1 kg of oxygen consumed. Heat Release Rate (HRR) is calculated from the oxygen concentration in the flue gases.

Specimens in the test are burned in ambient air conditions while being exposed to a specific heat flux. Combustion gases are analyzed, and the quantity of smoke produced from the specimen is also measured. Output data are recorded for mass loss rate of the specimen, oxygen concentration, carbon monoxide and carbon dioxide concentrations, smoke density and fire effluent flow as a function of time. The data is manipulated by calculation to produce values like heat release rate, total heat release, effective heat of combustion, mass loss rate, and smoke extinction area.

By determining the quantitative data for a known amount of material at a bench scale, then theoretical extrapolations can be completed to estimate or predict the potential contribution of the material in the full-scale environment or installation.

TYPICAL OUTPUT SUMMARY OF A CONE CALORIMETER TEST

PARAMETER	DESCRIPTION
Time to Ignition time (s)	The time at which sustained flaming occurs
Time to Flame-out (s)	The time elapsed from the beginning of sustained flaming to the cessation of flaming activity
Peak Rate of Heat Release (kW/m^2)	The maximum amount of heat energy released from the specimen from the beginning of sustained flaming to the time of flame-out
Time of Peak Rate of Heat Release (s)	The time elapsed from the beginning of sustained flaming to the peak rate of heat release
Average Rate of Heat Release (kW/m^2)	The mean rate of energy release per area of burning material. Rate of Heat Release can fluctuate over time so it is often considered that the average rate of heat release is a better predictor tool than the peak rate of heat release
Total Heat Released (MJ/m^2)	The integrated area under the HRR curve over the test period
Initial Mass (g)	The specimen mass before exposure to the heat source
Mass at Sustained Flaming (g)	The specimen mass at the time at which sustained flaming begins
Final Mass (g)	The specimen mass at the time at which sustained flaming ceases
Sample Mass Loss (kg/m^2)	The amount of material consumed during testing
Peak Specific Mass Loss Rate [$g/(s \cdot m^2)$]	The maximum rate at which the test material is degraded to produce combustible fuels
Average Mass Loss Rate [$g/(s \cdot m^2)$]	The mean mass loss rate calculated when 10% of the specimen mass loss occurs and ending when 90% mass loss has occurred
Average Effective Heat of Combustion (MJ/kg) or (BTU/lb)	The measured heat release divided by the mass loss for a specified time period. This is the amount of heat generated per unit mass lost by a material, representing the calorific value of the consumed portion of the material
Caloric Content (MJ/kg) or (BTU/lb)	The amount of heat derived by dividing the total heat released by the original specimen mass
Peak Extinction Area (m^2/kg)	The maximum amount of smoke produced at any given time during testing, and expressed as an area per unit mass of consumed material
Average Extinction Area (m^2/kg)	This refers to the average "yield" of smoke over the full test period
MAHRE (kW/m^2)	The maximum average rate of heat emission
Total Smoke (m^2/m^2)	The total smoke parameter during the test. It is normalised for the surface area of the specimen
Rate of Smoke Production ($m^2/s/m^2$)	The rate of smoke production at a moment in time
Carbon Dioxide Yield (kg/kg)	The mass of carbon dioxide produced per mass of product combusted

PERFORMING THE CONE CALORIMETER TEST

THE TESTING APARATUS

The test apparatus consists of an electric heater whose conical shape gives rise to the name of the test. The heater delivers uniform radiant heat flux to a sample within a range of 0 to 100 kW/m2. The test specimen is placed in a holder, which is mounted on a load cell that records the weight of the sample during the entire experiment.

A specified and consistent airflow is established (in air) through the apparatus ducting, the desired heat flux is achieved, and the baseline oxygen concentration and duct temperature readings are established.

In most cases, a spark igniter, situated above the specimen surface and below the cone heater, is used to ignite the products of combustion that are produced by the specimen as it thermally degrades, leading to flaming combustion of the material. When the entire specimen area is burning, the igniter is deactivated. In some instances, a spark igniter is not used.

The fire effluent gases travel upward into an instrumented hood system situated above the heater where the products of combustion are then analyzed. Such data is then used to calculate several different combustion parameters.

WHAT CAN BE TESTED

Cone calorimeter testing can apply to many types of materials and products, including solids and liquids. Some examples are building and construction materials, interior passenger vehicle finishes, heavy rubber materials used on rail-cars and liquid chemicals. Composite systems that comprise of multiple materials can be tested as well, as long as they can meet the specimen requirements.

Products that undergo physical changes when heated, such as intumescence or warping, along with dimensionally unstable materials, can be tested with the use of special mounting and restraining equipment to retain them adequately within the specimen holder during combustion.

Tests are typically conducted with the cone mounted in a horizontal position, but vertical orientation is also possible, depending on the end-use of the product.

SAMPLE REQUIREMENTS

Specimens that need to be tested should be as representative of the end-use products as possible.

To fit in the testing equipment, specimens should be 100 mm x100 mm (4 inches x 4 inches) with a tolerance of -2 mm and +0 mm, and up to 50 mm (2 inches) thick.

A minimum of 3 replicate specimens are typically required, but single specimens can be tested for preliminary screening purposes.

ADVANTAGES OF CONE CALORIMETER TESTING

The main advantage of a cone calorimeter test is that relatively small sample sizes are utilized, which makes it cost-effective in terms of the amount of material required. Smaller sample sizes also allow for easier transportation and lower shipping costs.

Additionally, a cone calorimeter test

- Is fast, safe and accurate with immediate results
- Can test multiple samples and inform about the differences between them
- Affords comparable testing capabilities for a full range of materials.

CONCLUSIONS

Determining the flammability properties of a material can be a vital tool in predicting potential fire risk and to aid in assuring the safety of people and operations in any industry.

In recent years, the cone calorimeter has emerged as the most widely used apparatus to determine the potential heat that can evolve in a fire. Due to the relatively small specimen sizes used for the test, cone calorimeter testing is a cost-effective way to research the fire performance of products while still in the developmental stage, for assessing material compliance to established performance requirements, as on-going quality control, or even to generate data for litigation purposes.

Element is a global provider of testing, inspection and certification services for a diverse range of materials and products in sectors where failure in service is not an option. We are trusted by many of the world's best organizations to test and advise on the safety, quality and performance of their products and operations.

For cone calorimetry testing, our accredited laboratories can provide testing according to ISO 5660-1, ASTM E1354, CAN/ULC-S135 and AS/NZS 3837.

REFERENCE

ASTM E1354 – Standard Test Method for Heat and Visible Smoke Release Rate for Materials and Products using an Oxygen Consumption Calorimeter

CAN/ULC-S135 – Standard Test Method for th Determination of Combustibility Parameters of Building Materials using an Oxygen Consumption Calorimeter

GLOSSARY

Burning behaviour - all the physical and/or chemical changes that take place when a material or product is exposed to a specified ignition source.

Effective heat of combustion - the amount of heat generated per unit mass loss by a material, product or assembly, when exposed to specific fire test conditions.

Fire performance - response of a material, product, or assembly in a particular fire, other than in a fire test involving controlled conditions.

Heating flux - the incident flux imposed externally from the heater on the specimen at the initiation of the test. The specimen, once ignited, is also heated by its own flame.

Heat release rate (HRR) - the heat which is released by the specimen, per unit of time.

Ignitability - the propensity of ignition, as measured by the time to sustained flaming, in seconds, at a specified heating flux.

Oxygen consumption principle - the expression of the relationship between the mass of oxygen consumed during combustion and the heat released.

Reaction-to-fire testing - the performance of a material or system in a fire situation with regard to the amount and rate of heat evolved, the amount and rate of spread of flame and the amount and rate of smoke and toxic fume evolved. These tests expose a material to a defined combustion challenge. Then observations are made to that material to determine relative fire damage.

Smoke production rate - product of the volumetric flow rate of smoke and the extinction coefficient of the smoke at the point of measurement.