PRODUCTIVITY THROUGH TECHNOLOGY

PROCEEDINGS FROM
NINTH ANNUAL STRUCTURAL FRAM CONFERENCE
AND PARTS COMPETITION

"Productivity Through Technology"

Proceedings of the S.P.I.
Ninth Annual Structural Foam Conference

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"Productivity Through Technology"

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Abstracts

THE STATE OF THE ART IN PROCESSING THERMOPLASTICS CONTAINING BLOWING AGENTS, WITH SPECIAL CONSIDERATION OF THE GAS COUNTER-PRESSURE AND CO-INJECTION MOLDING PROCESS

Dr. Kurt Alex

Structural foam is finding increasing application as a modern means of manufacturing a variety of products. The structural properties and design advantages of a part with a solid skin and foam core have become commonplace in many areas of industry, while in others the concept of structural foam is still in its infancy. On the whole, structural foam parts are manufactured using methods similar to conventional injection molding. Foaming, however, is achieved through addition of a blowing agent and the pressure of the expanding gas replaces the holding pressure function of conventional injection molding.

In the course of the past 10 or so years several structural foam molding techniques have been introduce and variants thereof are undergoing continuing development. Nevertheless, it is possible to classify the various techniques in use today on the basis of certain general characteristics. Such a classification leads first of all to a distinction between single-component and two-component (or co-injection) techniques. A further distinction can also be made on the basis of low-pressure or high-pressure clamp, and within each of these categories there are also various molding techniques such as the gas counter-pressure technique, expanding mold technique and thermocycling technique.

The present paper is an attempt to review the state of the art in the rapidly developing field of structural foam molding.

STRUCTURAL FOAM AND THE MODULAR PACK MINE SYSTEM

Jack Peterson

A case history of a military application utilizing structural foam to solve a difficult enclosure problem.

THE HOWS AND WHYS OF MOLD TEXTURING

Martin D. Pallante

This paper will discuss, in detail, what designers, mold builders, and structural foam molders should know about mold texturing and how it can be applied to their needs and employed to their best advantage.

The presentation will also explore and review the texturing procedure with particular emphasis placed upon the pattern selection process. We will take an in depth look at the types and styles of standard patterns that are available, how to specify them and how to control their influence on design parameters. Custom designed textures will also be studied in detail.

The paper will also deal with texture as a design consideration. Included in this broad heading will be such topics as draft angle requirements relevant to texture depths, mold material selection, the grain structure of metals and how it affects texture appearance and finally mold surface preparation.

Finally, the paper will present a structural foam case study which will graphically demonstrate the capabilities of mold texturing.

FINISHING BUSINESS MACHINE STRUCTURAL FOAM PARTS

Charles D. Storms

I. INTRODUCTION
II. PROBLEMS IN FINISHING THERMOPLASTIC FOAMS
  A. Swirls and Varying Densities
  B. Pinholes and Craters
  C. Blisters
  D. Bubbles
  E. Wicking
  F. Adhesion
III. SOLUTIONS IN FINISHING THERMOPLASTIC FOAMS
  A. Molding Solutions
  B. Solutions to Pinholes, Blisters, and Wicking
  C. Solutions to Hiding Swirls
  D. Electromagnetic Shielding
IV. COATING AVAILABILITY
  A. EPA Requirements
  B. High Solids
    1. Advantages
    2. Disadvantages
  C. Waterborne
    1. Advantages
    2. Disadvantages
V. TYPICAL BUSINESS MACHINE SPECIFICATION
VI. CONCLUSION

The fact that structural foams may be successfully finishing for decorative and functional purposes is the reason that foam will continue to penetrate the business machine market. New high solids and waterbase coatings will be required to meet EPA regulations. These new coatings will solve the problems inherent in finishing foams.

Comment: Paper will be updated with latest coatings developments.

THE FARREL/USM STRUCTURAL FOAM PROCESS

G. Bruce Robertson

This paper defines the Farrel/USM structural foam process and tells briefly how the process works as it is used by a custom molder. The major advantages and disadvantages of the process are discussed.

In the appendix 12 different business machine covers are evaluated as candidates for beneficial application of this process.

THE QUANTITATIVE MOLDING AND FINISHING EFFECTS OF MOISTURE IN POLYCARBONATE ON THE PHYSICAL AND CHEMICAL PROPERTIES OF STRUCTURAL FOAM

Herbert L. Jones and Rican Yu

It has long been established that the moisture content in polycarbonate thermoplastic resins in excess of 0.10% by weight can have decidedly adverse effects on the impact, flow, and numerous other physical/chemical properties. This inter-relationship between moisture content and physical/chemical molding and finishing properties of a polycarbonate product is exaggerated in thermoplastic foam products where the properties of the molded foam are affected along with the ability to paint and metallize the product.

It is the purpose of this paper to emphasize these inter-relationships and to describe practical, effective methods by which one may utilize a well-equipped chemical and physical laboratory to avoid practical problems in a plant BEFORE they occur, rather than catching them prior to or after shipment to a customer.

The chemistry of the moisture "reaction" with polycarbonate is described, along with the quality control testing techniques employed to minimize or eliminate the effects of moisture on polycarbonate in a modern structural foam processing plant.

QUALITY CONTROL IN THE STRUCTURAL FOAM PLANT

Ed Croft

The need for quality control is obvious, the methods needed to make Quality Control compatible with production goals is not so clear. This paper attempts to describe one approach and its efforts.

INCREASED PRODUCTIVITY THROUGH MULTIPLE MOLD MOUNTING AND SEQUENTIAL INJECTION

Joseph W. Scott

One of the primary advantages of multi-nozzle SF machines has always been the ability to mount several molds on the platens and making several parts in the same shot. But balancing the nozzles for optimum material flow, to avoid packing one part and underfilling another, has always been troublesome. This paper, describing a technique first used in a custom molding plant, and then developed and refined by a machinery manufacturer, describes the hardware necessary, the operation, and the advantages of filling each of several molds separately and independently in the same cycle; and how this technique maximizes scheduling and production efficiency in a large SF custom molding operation. A further advantage is demonstrated in the technique's ability to increase the total available clamping force, since only a fraction of that force is required for clamp holding pressure between each sequential mold fill. Total shots have been achieved which would require double the machine's normal clamping force, had the sequential injection technique not been used.

START WITH THE FINISH

Buck Larson

Production finishing of structural foam parts sometimes presents major problems which could be eliminated or at least reduced if the product was designed and molded with the finish in mind. This paper presents concerns, from the point of view of the production finisher and shielder, which should be considered by designers and molders as the product evolves from conception to the market. All too often prototypes are finished in a laboratory setting and little concern is made for how the job can be done in mass production. By starting with the finisher, some helpful cost saving suggestions can be made.

PLASTIC ENCLOSURE EMI SHIELDING SYSTEMS AND DESIGN OPTIONS FOR COMPLIANCE WITH REGULATORY AGENCY, EMI, ESD AND SAFETY REQUIREMENTS

Gary S. Ross

Safety is a key factor that has attracted the attention of numerous electromagnetic interference (EMI) regulatory agencies. The causes of EMI include natural and manmade sources; lightning and sunspot activity are natural sources of EMI, while motors, power lines, transformers, fluorescent lights, personal computers and electronic games are all sources of manmade EMI. In addition to EMI shielding, electrostatic dissipation is a serious problem. Static discharges to the plastic case or static buildup and subsequent discharge may cause equipment malfunction and possible damage to semiconductor chips. Many new products and devices that utilize semiconductors, integrated circuits, or digit electronics are sensitive to electromagnetic radiation and static discharge. Truck brakes and medical devices are examples of products whose advanced circuitry is sensitive to EMI, and consequently require regulations to ensure safety from unexpected malfunction. The diversity of electronic products in various fields accounts for various EMI regulatory agencies that are limiting the strength of radiation emissions.

As plastic rapidly supplants sheet metal as the preferred cabinet metal, manufacturers are discovering that the employment of commercially available shielding aids combined with little to moderate equipment redesign, enables their products to effectively comply with EMI regulations as well as with Underwriter Laboratories (UL) safety requirements. Shielding aids such as metal coatings and filters, cover a broad spectrum of EMI related problems from shielding plastic cabinets (eg. conductive coatings) to reducing conducted EMI in power lines.

PROCESS AND PRODUCT MIX: THE KEYS TO BEING A SUCCESSFUL SUPPLIER

Roger Herrick

This paper will outline the necessary required capabilities for a company to be successful in structural foam molding, finishing and assembly. It will highlight required engineering services to aid the customer or the designer in achieving optimum results in the proposed structural foam article.

We will talk about the many processes embraced currently in injection molding, finishing, shielding and assembly. We will touch briefly on the needs to be aware of a proper product mix to utilize those facilities and capabilities. We will also discuss the limitations of structural foam and endorse alternate process methods to accommodate volumes not considered acceptable in structural foam from the view point of tooling and setup cost.

I think this paper is badly needed to assure the growth of applications in thermoplastic injection molded structural foam.

STRUCTURAL URETHANE FOAM COMPOSITES BY THE RIM PROCESS

M. F. Mann

Approximately two years ago, a new production process for automobile door liners was introduced in Europe. The process consisted of stretching a sheet of unsupported, expanded PVC over the mold cavity. The mold was closed and clamped and a polyurethane structural foam mixture was injected by the RIM method through the top half of the mold. The pressure and temperature of the expanding mixture forced the vinyl to conform to the contours of the cavity thus producing a finished door liner (structural foam/vinyl composite). This process showed promise but had several drawbacks. Over the past year, cycle times have been reduced to 2 minutes, intricate surface detail has been achieved and other formable surfaces have been substituted for the vinyls.

These improvements have not only made it a candidate product for the US auto industry but has found applications in non-automotive areas. This paper will detail the process, properties and discuss its various uses.

COMMUNICATIONS—A DESIGNER'S TOOL

Grover Boothman

A description of a system and sequence of communications that will assist the Product Designer in the design and development of a new product.

MEDICAL INSTRUMENTATION APPLICATIONS; CASE STUDIES

Vincent A. Perla

The use of structural foam in medical instrumentation equipment has increased at least 15% per year in recent years, and this increase has resulted in a vastly expanded market for structural foam applications.

Two such applications are described in this presentation, namely, the Xerox 110 Dental Imaging System and the Ohio Intensive Care Incubator.

The selection of structural foam for these applications not only improved the cosmetic appearance of these units but provided more functional uses.

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Combustibility of Structural Foam Plastics

Gordon L. Nelson
General Electric Co.

Engineering Structural Foam is increasingly replacing sheet metal, metal castings, and SMC in a variety of large part applications in a number of growing industries. Business equipment manufacturers, in particular, have come to realize that specification of structural foam means significant increases in performance and cost savings over metal. Point-of-sale terminals, printers, CRT's, even whole work stations, are being produced in structural foam. There is increasing interest for automative and for transportation applications. The appliance and materials handling industries are also deeply involved in the use of structural foam. With the expanding use of engineering structural foam and the growing number of tougher fire safety regulations it becomes more important to know how well a material performs under fire circumstances.

All organic or polymeric materials burn under sufficient fire stress. Metals as well can be severely damaged in a fire. Fire safety is thus a question of the relative behavior of materials in real applications subjected to a range of real fire circumstances. It is important to know what role materials play in a fire situation; whether they contribute significantly to a fire scenario. It is important to know whether and how much flame retardancy is required, and what information standard test methods give.

Unfortunately, little work has been done on the large-scale fire behavior of structural foam plastics, particularly for the main stream applications of business machines, EDP equipment and other electrical/electronic enclosures. Little information is known as to the relationship of small laboratory tests used for these applications and their predictiveness to real fire behavior.

The Combustibility Committee of the Structural Foam Division of SPI discussed this critical need at some length and solicited proposals from interested test laboratories. Underwriters Laboratories, Northbrook, Illinois, was chosen as the contractor.

The purpose of the test program was not relative material performance evaluation, although a number of structural foam materials were used, but rather understanding the real fire parameters involved in the use of structural foam in electrical/electronic housings and examining the relationship of large and small scale fire test results. The purpose of this report is to give one person's interpretation of the results of that SPI/UL study.[1]

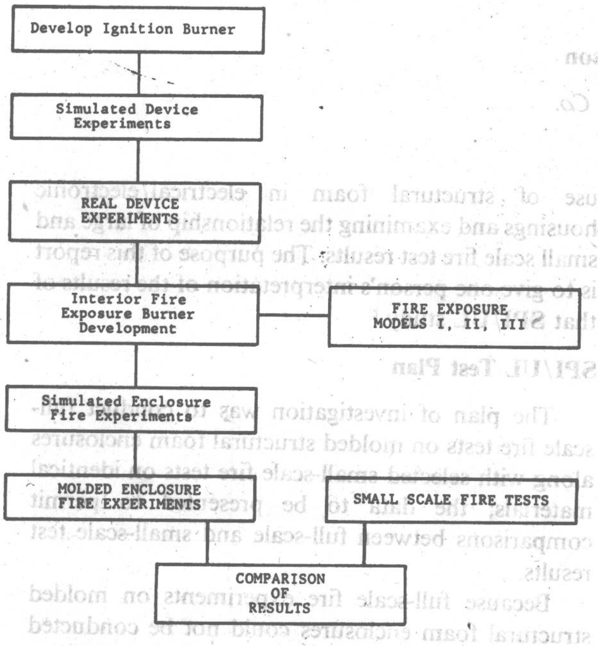
SPI/UL Test Plan

The plan of investigation was to conduct full-scale fire tests on molded structural foam enclosures along with selected small-scale fire tests on identical materials; the data to be presented to permit comparisons between full-scale and small-scale test results.

Because full-scale fire experiments on molded structural foam enclosures could not be conducted until a generalized test procedure had been established, an experimental program shown in the following Flow Chart was conducted. It consisted of the following steps:

1. Develop an ignition source that would cause ignition and sustained burning of printed wiring boards and components contained within electronic enclosures and to quantify that ignition source.
2. Conduct fire experiments on simulated electrical/electronic devices to establish experimental methods and gain experience using the ignition source.
3. Conduct fire experiments on real electrical/electronic devices.
4. Develop representative simulated interior fire exposures based upon the experience and knowledge developed from the real device fire experiments.
5. Conduct fire tests using the simulated fire exposures on enclosures fabricated from structural foam sheet to finalize test procedures prior to conducting molded enclosure experiments.
6. Conduct fire tests on structural foam enclosures molded in five thermoplastics commonly used for that purpose.
7. Conduct small scale fire tests on samples cut from molded enclosures identical to those that were subjected to the full scale fire experiments.
8. Provide a means of comparison of the full scale and small scale test results.

SPI/UL TEST PLAN



An Ignition Source

The basic premise was to examine what happens given *sustained* ignition of printed wiring boards in an electrical/electronic device. That, of course, is the key assumption, and clearly an abnormal situation. Printed wiring boards are known to be difficult to ignite. Also, tests on television receivers have shown that about 40 watts is the highest energy dissipation rate achieved by artificially stressed and shorted electrical components, thus the actual available energy is low in many circumstances. (The energy release rate by the bunsen burner in UL-94 is approximately 60 watts).[1]

Numerous small ignition sources were tried: flammable liquids in small pans, propane torches, and propane fired sand burners. Only the latter proved both quantifiable and gave sustained ignition of printed wiring boards. Thus an approx. 4 inch x 4 inch x 4 inch sand burner was chosen (Figure 1), propane at 4g/min for 4 minutes was the fuel, the burner was located 2 inches below the printed wiring boards to be ignited. The energy release rate for the sand burner is approximately 3000 watts. The low probability of such a severe ignition source is (and must be) recognized. However, its use allows us to examine what happens when a sustained fire exists, and to determine what size fires are achievable. A good deal of work was spent in quantifying and understanding the ignition source and its effects upon printed wiring boards. And in general printed wiring boards as presently produced *are* difficult to ignite.

SAND BURNER

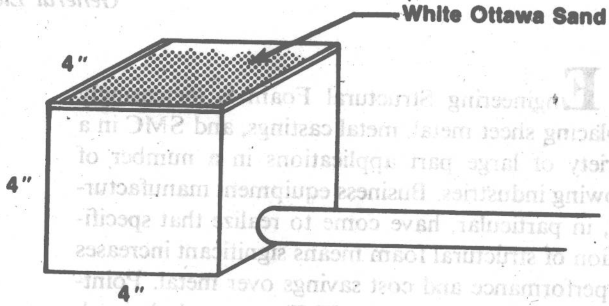


Figure 1. 4 inch by 4 inch by 4 inch Sand Burner. Propane is fed to the burner at 4g/minute for 4 minutes. The burner is placed 2 inches below the printed wiring boards of the device to be ignited. The energy release rate is approximately 3000 watts.

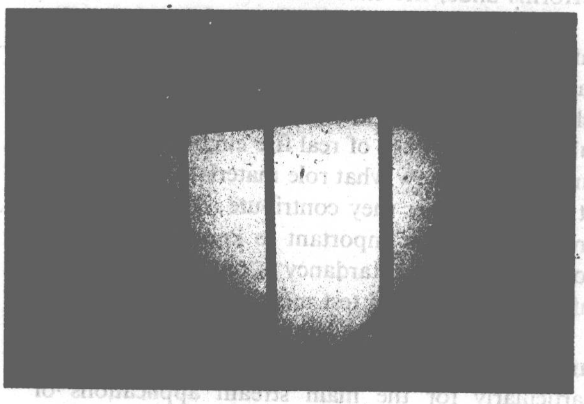


Figure 2. Fire Experiment Room. Simulated devices are placed at the center of this 12 feet long, 8 feet wide, 8 feet high test room. There is a standard door opening located in an 8 foot wall (left), opening to an 8 feet wide, 4 feet deep, 22 feet high hood assembly. Analytical measurements are made in the experiment room and in the hood.

Ignition of Electrical/Electronic Devices

With a suitable ignition source the next step was to burn electrical and electronic devices. The experimental technique was verified by burning 5 simulated devices utilizing portable television enclosures, both metal and plastic. Television enclosures were selected because they are in the middle of the size range for electronic enclosures and easy to obtain. Television printed wiring boards were used in various configurations to simulate electrical contents. The simulated devices were positioned at the center of a fire experiment room 8 feet wide by 12 feet long by 8 feet high (Figure 2). The room contained a standard door opening located in the center of an 8 foot wall. The room was located within a 47 foot high fire test building.

A 6 inch x 6 inch opening was cut in the bottom of the television enclosures to provide entrance for the ignition burner flame. The burner was positioned 2 inches below the printed wiring board contained in the device. Propane fuel was fed to the ignition burner at the rate of 4 g/min. (Figure 3).

In these experiments temperatures were measured within the television enclosures for tests both with and without printed wiring boards and components present. Various horizontal and vertical orientations of the printed wiring boards were used. These experiments provided an understanding of how real devices might perform in a full-scale fire situation. It was observed that a definable time/temperature curve was possible per square inch of printed wiring board involved.

The temperature and duration of the fires and the volume of smoke and combustion gases released into the test room during the burning of devices was observed. From this experience procedures were established for the conduct of real device experiments.

Seven fire experiments were conducted using electrical and electronic devices obtained on the open market. They were selected to represent typical electrical/electronic devices and included:

— a black and white television
— two data processing terminal/printers
— two color television consoles
— a point-of-sale terminal
— an electronic cash register

The purpose of these experiments was to obtain data on the temperature, heat flux and smoke which may be developed due to abnormal ignition of printed wiring board(s) in the devices.

All of these experiments were conducted with the devices located at the center on the floor in the fire experiment room. Temperature, heat flux and gas analysis instrumentation was used. Concentrations of oxygen, carbon monoxide, carbon dioxide and methane and smoke density were measured in the test room. Ten thermocouples were also installed on the interior surfaces and in interior spaces of the devices tested to measure the temperatures developed within the device enclosures. Two heat flux calorimeters were used in these experiments. One was located 3 feet above the room floor directly above the device to measure the heat flux emitted upward. A second was installed in a small hole located at the approximate center of a vertical side of the device to measure the interior heat flux levels developed during the fire tests.

The ignition source was the same ignition burner previously described for the simulated device experiments, i.e., the 4" x 4" x 4" sand burner. It was located 2 inches below the main printed wiring board(s) contained within each device (Figure 3).

Needless to say, a large quantity of data was

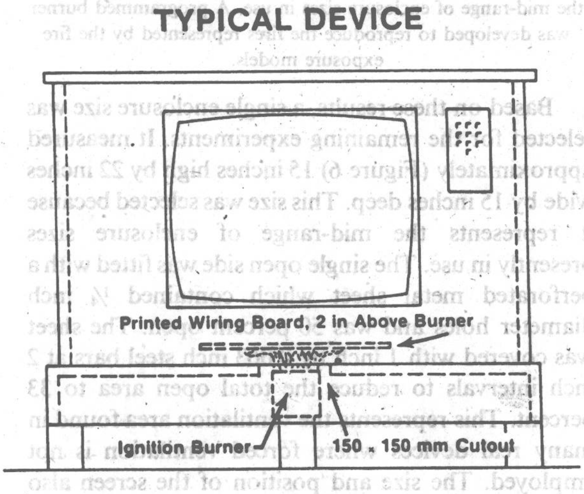


Figure 3. Typical Device Test Configuration. The sand burner is placed 2 inches below the major horizontal printed wiring board through a 6 inch by 6 inch cutout in the bottom of the test device.

Figure 4. Real Device Experimentation Progress. Flames are clearly visible in this photo at six minutes after ignition of the sand burner.

developed by burning the real devices (Figure 4). The data showed wide variations among the devices and confirmed that a number of variables exist which may directly influence the development of an interior fire. These variables include: (1) size or volume, (2) thermal insulative properties of the enclosure material, (3) ventilation (area and position), (4) quantity and type of interior components, (5) position of the printed wiring boards, and (6) location of metal panels and shields which may act as heat sinks. While the specific data may be useful for the evaluation of specific devices, it was not sufficient for generalized observations. For that purpose, a reproducible model for the devices was needed.

Numerous electronic devices were examined by UL to observe the arrangement and concentration of printed wiring boards. In devices containing a single horizontal board, the printed wiring board covered from 13 to 80 percent of the base area, and there was between 0.01 and 0.03 square inch of board per cubic inch of volume of the enclosure. In most cases the board was located near the bottom of the enclosure. This condition produced the least severe interior fires in the device experiments. Other devices which contained a combination of vertical and horizontal boards produced interior fires of intermediate severity. The most severe fire condition occurred in devices which contained a closely stacked array of vertically oriented printed wiring boards which filled the enclosure.

Thus, the experience gained from real device examinations and fires led to the definition of three Fire Exposure Models (Figure 5). In these models three different configurations of printed wiring boards were used to represent the arrangements found in real devices. The models were developed to represent the range of fire potential which can be encountered in electronic devices. The models are characterized by area of printed wiring boards per unit volume of enclosure. Model I contains 0.04 in² of wiring board per cubic inch of enclosure (least severe fire potential), Model II contains 0.16 in² of wiring board per cubic inch (intermediate severity fire potential), and Model III contains 0.73 in² of wiring board per cubic inch (most severe fire potential). The area/volume relationship of some of the real devices which were burned were reported. For example, the terminal/printer used in the experiments was found to contain 0.64 in²/in³ (board/volume) in the vertical array section (Model III, Most Severe) and the B/W TV receiver contained 0.03 in²/in³ (board/volume) in the enclosure (Model I, Least Severe).

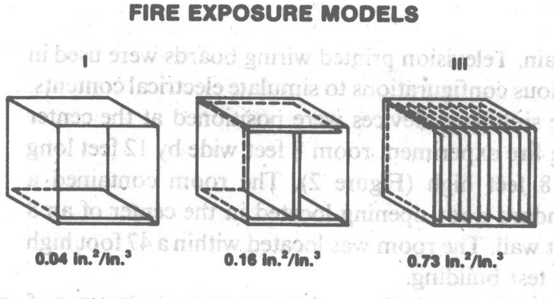


Figure 5. Fire Exposure Models. Three models were developed to represent the range of fire potential encountered in electronic devices. These models are characterized by increasing area of printed wiring boards per unit volume of enclosure. Typical values of board area/enclosure volume are shown under each model.

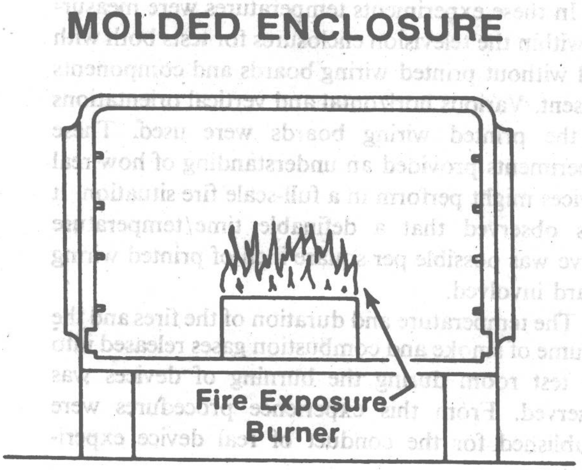


Figure 6. Molded Enclosure. Comparisons of materials were conducted on enclosures measuring approximately 15 inches high by 22 inches wide by 15 inches deep. This size represents the mid-range of enclosure sizes in use. A programmed burner was developed to reproduce the fires represented by the fire exposure models.

Based on these results, a single enclosure size was selected for the remaining experiments. It measured approximately (Figure 6) 15 inches high by 22 inches wide by 15 inches deep. This size was selected because it represents the mid-range of enclosure sizes presently in use. The single open side was fitted with a perforated metal sheet which contained ¼ inch diameter holes and was 50 percent open. The sheet was covered with 1 inch by 0.063 inch steel bars at 2 inch intervals to reduce the total open area to 33 percent. This represents the ventilation area found in many real devices where forced ventilation is not employed. The size and position of the screen also permitted visual observation of the interior of the enclosure.

Development of Model Fires

The next task was to develop a reproducible, synthetic fire representative of the model conditions. The development of an interior fire exposure burner to be used in the experiments with molded enclosures took place in two steps. The first step was to measure the interior fire conditions defined by the three models, using the specific enclosure volume defined. The second step was to reproduce these interior fire conditions using a sand burner with a programmed propane firing rate.

The interior fire conditions for Models I and II (Least and Intermediate exposure) were experimentally determined by burning printed wiring boards in a noncombustible enclosure. This enclosure was constructed of ½ inch calcium silicate board and the open side was covered with perforated metal sheet to provide 33% ventilation. Its dimensions were 15 inches high by 23 inches wide by 15 inches deep, closely approximating the size of the molded enclosures to be used in subsequent experiments.

For Model I, which produced the least severe fire exposure, 210 square inches of printed wiring board were used, resulting in a 0.04 square inches of wiring board per cubic inch of enclosure.

For Model II, which produced the intermediate severity fire exposure, 665 square inches or printed wiring boards were used, resulting in a 0.13 square inches of wiring board per cubic inch of enclosure. Subsequent experiments with Model II exposure indicated that further development of a Model III exposure would provide no additional meaningful data and the Model III exposure was not used.

In these experiments a 6 inch by 6 inch opening was cut in the base of the noncombustible enclosure to permit the entrance of the standard ignition burner flame. The two configurations of printed wiring board materials were located 1 inch above the base of the enclosure. The upper plane of the ignition burner assembly was located 2 inches from the underside of the printed wiring board. The ignition source was the same as used in the real device experiments (4″ x 4″ x 4″ sand burner, 4 min duration at 4 g/min propane fuel).

Four thermocouples were located 1 inch below the top of the inside surface of the enclosure to measure internal temperatures. Two heat flux calorimeters were installed in the enclosure surfaces to view the wiring board fire from the top directly above the burner and from the side at one-half the height of the enclosure.

Figures 7 and 8 show the time-temperature curves for the exposure conditions. In each illustration, Curve 1 is the temperature produced by the ignition burner flame alone, and Curve 2 is the temperature produced by the ignition burner and the printed wiring board(s) together. Curve 3 is the difference between Curves 1 and 2 and is an estimation of the contribution time-temperature curve *attributable to the burning printed wiring boards alone.*

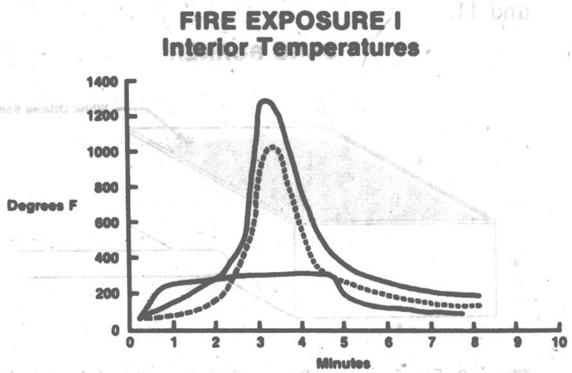


Figure 7. Time-Temperature Curve Development—Model I. Lowest curve represents the ignition burner flame alone. The highest curve represents the ignition burner plus the flame produced by the burning printed wiring boards. The dotted curve represents the time-temperature curve attributable to the burning printed wiring boards alone.

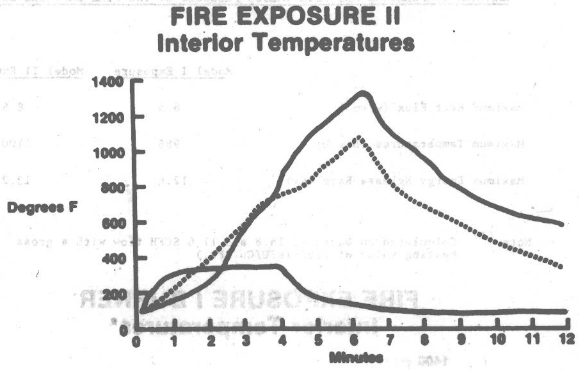


Figure 8. Time-Temperature Curve Development—Model II. Lowest curve represents the ignition burner flame alone. The highest curve represents the ignition burner plus the flame produced by the burning printed wiring boards. The dotted curve represents the time-temperature curve attributable to the burning printed wiring boards alone.

A fire exposure burner was then designed to reproduce the time-temperature curves developed by burning printed wiring boards alone. This was an 8 inch by 8 inch by 4 inch deep propane-fired sand burner (Figure 9). It was installed inside and at the center of the bottom of the enclosure (Figure 6). The propane-firing rates were determined experimentally to reproduce as closely as possible the temperature Curve 3 in Figures 7 and 8 which is attributable to the burning printed wiring boards alone.

Table 1 shows the maximum temperature and heat fluxes recorded within the enclosure with the programmed fire exposure burner. The calculated maximum energy release rate of the propane used in this burner is also shown. The close approximation of the Fire Exposure Burner curves to the burning printed wiring board curve is shown in Figures 10 and 11.

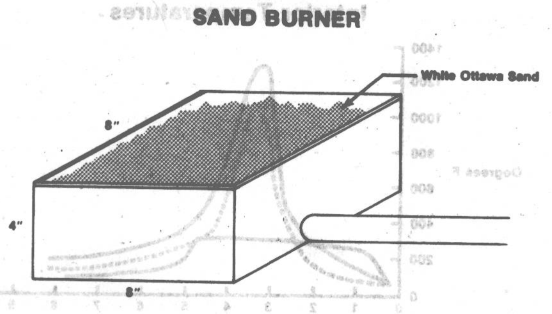


Figure 9. Fire Exposure Burner. This is an 8 inch by 8 inch by 4 inch sand burner. Propane is fed at a programmed rate to reproduce the dotted time-temperature curves of Figure 7 and 8. The burner is installed inside and at the center of the bottom of the test enclosure (Figure 6).

Table 1

MAXIMUM TEMPERATURE AND FLUX VALUES PRODUCED BY THE FIRE EXPOSURE BURNER

	Model I Exposure	Model II Exposure
Maximum Heat Flux (w/cm^2)	6.5	8.5
Maximum Temperatures (Deg D)	985	1100
Maximum Energy Release Rate (Kw)[1]	12.6	13.2

Note [1] Calculated on basis of 16.8 and 17.6 SCFH flow with a gross heating value of 2560 (BTU/Cu. Ft.)

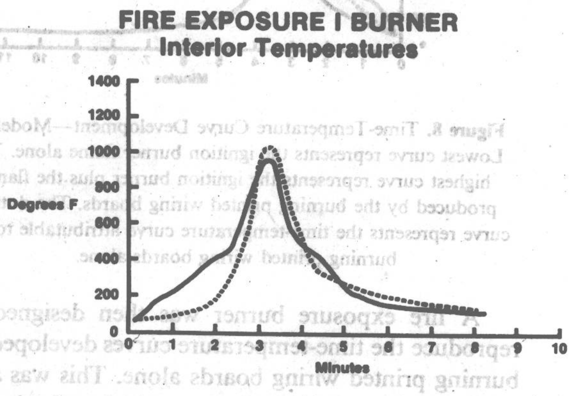


Figure 10. Model I Burner Flame. The dotted line is the experimental time-temperature curve as determined in Figure 7. The solid line is the time-temperature curve as reproduced by the programmed fire exposure burner.

The average enclosure temperatures produced by this fire exposure burner were somewhat higher than those actually observed within most of the real device experiments. This was because the calcium silicate enclosure was more insulative than most of the real device enclosures. Also the volume of some of the devices was considerably larger than the selected enclosure size. In one case, the real device contained a metal plate which acted as a heat sink and in two other real devices the ventilation slots were located directly above the array of printed wiring boards, which did not allow the heat of the internal fire to be contained.

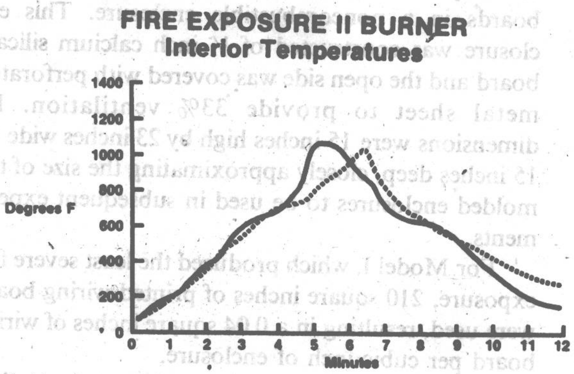


Figure 11. Model II Burner Flame. The dotted line is the experimental time-temperature curve as determined in Figure 8. The solid line is the time-temperaure curve as reproduced by the programmed fire exposure burner.

The heat flux values recorded in the real devices were much lower than that produced by the fire exposure burner. It should be noted that the real devices contained many internal components which prohibited a total view of the internal fire by the calorimeter, while the calcium silicate enclosure contained only the fire exposure burner which was directly viewed by the heat flux instruments.

Enclosure Tests

Six enclosures fabricated from structural foam plastic sheet were used to qualitatively observe the effect of the programmed fire exposure burner on four different materials commonly used in molded enclosures and to confirm experimental technique.

These enclosures had the same dimensions as the non-combustible enclosure and contained the same temperature and heat flux instrumentation as that used in the development of the fire exposure burner. Propane firing rates were programmed to represent the fire exposures associated with Models I and II.

Table 2 shows the results of these experiments. Model I Exposure (representing one horizontal printed wiring board) is capable of causing sustained burning of two of the four materials. Model II Exposure (representing two horizontal and two vertical printed wiring boards) is capable of causing sustained burning of three of the four materials. The fourth material melts through without ignition. Thus these severe model exposures were capable of taking the enclosures to the point of failure. This was essential if the full scale data were to be compared with small scale fire test results.

Table 2

TEST RESULTS

Experiment No.	Material Code	Fire Exposure	Results	Experiment Duration Min:Sec
E1	G	I	No significant damage	4:00
E2	K	I	3:45 bottom surface ignites	3:55
E3	H	I	3:45 bottom surface ignites	4:00
E4	F	I	Slight discoloration and distortion	4:00
E5	F	II	Top of unit melted through at 6:38; no other involvement	10:00
E6	G	II	5:45 bottom surface ignites	6:00

Molded Structural Foam Enclosure Tests

Structural foam plastic enclosures molded from five different thermoplastic formulations were exposed to the two fire exposure conditions represented by Models I and II. The materials were selected to represent the range of foamed polymeric material presently being used by industry to produce molded structural foam enclosures. All of the enclosures were made in the same mold to produce identical samples. The inside dimensions of the enclosures were approximately 14 inches high, 22 inches wide by 15.5 inches deep. Walls were approximately ¼ inch inches thick. The back, top and sides within the enclosure had ribs (Figure 12).

The programmed fire exposure burner was used to produce Model I and II fire exposures. The fire exposure burner was located at the center of the inside bottom surface of the enclosures. The open side of the enclosure was covered with the perforated metal sheet as used in earlier experiments to provide 33% ventilation.

Figure 12. View of Molded Enclosure Under Test. The fire exposure burner flame is shown in center of enclosure. Heat flux instruments are visible in front of and on top of the molded enclosure. The molded enclosure is completed by mounting perforated sheet metal over the open side to provide 33% ventilation.

The end point of each experiment was defined as the time at which the bottom surface of the enclosure became involved in fire. However, if an end point was reached the fire exposure burner was continued for the full programmed time period to permit the acquisition of room environment data. After this time the enclosure fires were extinguished with a carbon dioxide extinguisher, therefore the data obtained did not result from burning the enclosures to completion.

Four thermocouples were installed through the bottom of each enclosure. These thermocouples were located 1 inch below the ribs molded into the inside upper surface of the enclosure at the center of each quadrant of the upper surface.

Within the fire experiment room, measurements were made of temperature, heat flux, oxygen concentration and smoke density. Oxygen concentration, smoke density, temperature and air velocity were also measured in the exhaust duct from the fire experiment room. Air velocity and flame plume temperatures were measured at the door.

Of the five different structural foam plastics used in the molded enclosure experiments (Figure 13), four were able to withstand Model I exposure fire; none of the five materials were able to withstand Model II exposure fire as shown in Table 3.

As a means of comparing results of the molded enclosure experiments, rankings of selected quantities are shown in Table 4. Ranking number 1 represents minimum fire development and 5 maximum fire development. The enclosure experiments were ranked on the maximum values of temperature,

MOLDED ENCLOSURE FIRE EXPERIMENTS
WEIGHT LOSS AND IGNITION RESULTS

Experiment No.	Material Code	Fire Exposure	Initial Wgt, Lbs	Weight Loss Percent	Ignition Time At Top	Ignition of Bottom
F1	A	I	25.5	0.0	2:40	No
F2	B	I	25.9	18.5	2:30	6:05
F3	E	I	27.6	0.0	2:35	No
F4	C	I	28.2	0.4	2:10	No
F5	D	I	27.7	0.4	2:10	No
F6	A	II	25.5	17.3	2:30	7:20
F7	E	II	28.2	14.9	4:10	6:50
F8	C	II	29.0	32.0	2:30	7:00
F9	D	II	28.0	43.6	2:03	5:35

Table 4

RANKING ORDER OF MOLDED ENCLOSURE RESULTS

Model I Exposure

Production Characteristic	1	2	3	4	5
Room Temperature Production	A	E	D	C	B
Room Smoke Production	E	A	C	D	B
Room Carbon Monoxide Production	A	E	D	C	B
Room Oxygen Depletion	A	E	D	C	B
Interior Temperature Production	E	A	D	C	B
Interior Radiant Flux Production	E	D	A	C	B
Ignition Time (longest time = 1)					
bottom	ACDE				B
top	A	E	B	C	D

Model II Exposure

Production Characteristic	1	2	3	4
Room Temperature Production	A	E	C	D
Room Smoke Production	A	E	C	D
Room Carbon Monoxide Production	A	E	D	C
Room Oxygen Depletion	A	E	D	C
Interior Temperature Production	A	E	C	D
Interior Radiant Flux Production	A	E	C	D
Ignition Time (longest time = 1)				
bottom	A	C	E	D
top	E	AC		D

Note: Material B was not used in Model II Exposure, since it ignited in Model I.

Figure 13. Molded Enclosure Experiment F2. The test view is shown at ½ minute into experiment. The molded enclosure is in the center of the test room. Note thermocouples and other instrumentation.

smoke, carbon monoxide, oxygen depletion and radiant flux. When similar values were obtained for two materials the additional criterion of the greatest area under time-temperature or time concentration curves was employed to establish the rankings.

Laboratory Scale Fire Tests

Molded structural foam enclosures identical to those used in the full-scale experiments were cut up to provide samples for laboratory scale fire tests.

Eleven small-scale fire tests were performed on each material. The small-scale tests were selected because they are frequently used to evalute fire performance characteristics such as ignitability, spread of flame, ease of flame extinction, smoke generation and the heat release rate of plastic materials.

The following are the laboratory scale tests employed.

Test No.	Reference No.	Title
1	UL-94	Test for Flammability of Plastic Materials for Parts in Devices and Appliances
2	ANSI/ASTM E162-78	Surface Flammability of Materials using a Radiant Heat Energy Source
3	ANSI/ASTM D2863-77	Measuring the Minimum Oxygen Concentration to Support Candle-like Combustion of Plastics (Oxygen Index)
4	——	Proposed Test for Heat and Visible Release Rates for Materials and Products (OSU Heat Release Calorimeter) (Ref. 2)
5	ANSI/ASTM E662-79	Specific Optical Density of Smoke Generated by Solid Materials
6	ANSI/ASTM D2843-77	Density of Smoke from the Burning or Decomposition of Plastics
7	ANSI/ASTM D1929-77	Ignition Properties of Plastics
8	ANSI/ASTM F501, FAR 25.853 Appendix F	Aerospace Materials Response to Flame, with Vertical Test Specimen
9	——	A Small-Scale Test for Evaluating the Surface Flame Propagating Properties of Polymers (Ref. 3)
10	UL-746	Test for Polymeric Enclosures of Portable Electrical Appliances
11	—	IEC Glow Wire Test

Seven laboratories participated in the test program (Table 5), thus for some of the tests reproducibility between laboratories was examined. Data for materials A through E are shown in Table 6 and between laboratory reproducibility shown in Table 7.

Table 5

PARTICIPATING LABORATORIES AND SELECTED SMALL SCALE TESTS

Test No.	Identification	S	T	U	V	X	Y	Z
1	UL-94	*	*	*	*	*	*	*
2	E-162	*	*		*			
3	D-2863	*	*	*	*	*	*	
4	OSU-HRR	*						
5	E-662	*	*		*			
6	D-2843	*						
7	D-1929	*						
8	F-501	*	*					
9	Downward Vertical Burning Rate				*			
10	UL-746A Hot Wire Test		*					
11	IEC Glow Wire	*						

Table 6

SMALL-SCALE TEST DATA†*

Tests	A	E	C	D	B
UL-94	VO 5V	VO 5V	VO 5V	VO 5V	V1 5V
FAR 25.853a	Pass	Pass	Pass	Pass	Pass
ASTM E162 Radiant Panel, Is	56	49	63	117	105
ASTM D2863 Oxygen Index	38.3	33.1	27.2	26.5	28.8
OSU Slope E (Kw/Sec.M^2)	0.33	0.96	0.89	1.40	2.19
Maximum Heat Release Rate (Kw/M^2)	180	206	253	252	346
OSU Smoke Release Rate (S/min. M^2)	370	530	2480	2870	1310
NBS Smoke (ASTM E-662) Dm (Flaming)	448	389	750	752	732
Dm (Smoldering)	82	86	791	577	346
(ASTM D2843) XP-2 Smoke Density Rating	79	69	96	95	94
Setchkin Ignition (ASTM D1929) - Self °C	560	560	470	400	475
- Flash °C	425	422	395	370	414
Downward Burning Rate at 100% O_2	5.6	5.0	15	12	17.5
UL-746A Hot Wire Ignition Test (Sec)	60	58	67	49	56
IEC Glow Wire Test					
Flame Height at 650°C (mm)	0	0	30-80	20-60	60-90
Flame Height at 960°C (mm)	20-60	20-60	30-70	20-80	20-120
Extinguishing Times 650/850/960°C (Sec)	0	0-4	0-1	0	5-21

† Data are average values for all reports from participating laboratories.

* These numerical flame spread ratings are not intended to reflect hazards presented by these or any other materials under actual fire conditions.

Table 7

ASTM E-162 RADIANT PANEL REPRODUCIBILITY*

Materials	Is, Laboratory S	T	V	Average
A	41	49	60	56
B	72	82	161	105
C	72	67	50	63
D	119	122	110	117
E	40	35	73	49

ASTM D-2863 OXYGEN INDEX TEST RESULTS

Laboratory Code / Material	S	T	U	V	Y	Average
A	38.1	36.8	38.5	36.8	41.5	38.3
B	29.6	26.1	29.5	30.9	28.0	28.8
C	26.7	24.8	27.5	27.1	30.0	27.2
D	26.0	23.4	26.5	27.9	28.5	26.5
E	32.4	29.7	35.0	32.3	36.0	33.1

* These numerical flame spread ratings are not intended to reflect hazards presented by these or any other materials under actual fire conditions.

One method that can be used in evaluating the relationship between full-scale enclosure experiments and small-scale fire tests is to rank the individual results. It is best to divide this ranking into three groups.

The first group of rankings compares the average extinguishing times of the small-scale tests

Table 8

IGNITION DATA

	Ranking Order 1	2	3	4	5
Full Scale					
Ignition Time					
Model I - Top	A	E	B	C	D
Bottom	AECD				B
Model II - Top	E	A	C	D	
Bottom	A	C	E	D	
Small Scale					
Setchkin Ignition Temperatures	AE		B	C	D
UL-94	AECD (V-0)				B (V-1)
IEC Glow Wire Test Extinguishing Times	AE		D	C	B
UL-94	D	C	A	E	B
FAR 25.853	D	A	E	C	B
UL-746A Hot Wire Ignition Test	C	A	E	B	D

UL-94 and F-501 and Setchkip ignition temperature data with the internal ignition times recorded during the molded enclosure experiments. These results are shown in Table 8.

The second group of rankings compares the room and interior enclosure temperatures, radiant flux levels and oxygen depletion data developed in the molded enclosure experiments with the burning rate, ignition temperatures, flame spread, heat release and ease of extinction information developed in the small-scale tests. The results of this ranking order are shown in Table 9.

Table 9

RANKING ORDER OF RESULTS RELATING TO TEMPERATURE AND HEAT FLUX

	Ranking Order 1	2	3	4	5
Full Scale					
Room Temperature Production	A	E	C	D	B
Room Oxygen Depletion	A	E	D	C	B
Interior Temperature Production	A	E	C	D	B
Interior Radiant Flux Production	B	A	E	C	D
Overall	A	E	C	B	D
Small Scale					
ASTM E-162 Radiant Panel	E	A	C	B	D
ASTM D-2863 Oxygen Index	A	E	B	C	D
Heat Release Calorimeter (OSU)	A	E	C	D	B
ASTM D-1929 Setchkin Apparatus	A	E	B	C	D
Downward Vertical Burning Rate	E	A	D	C	B
Overall	A	E	C	B	D

The third group of rankings compares the visible smoke and carbon monoxide levels developed in the molded enclosure experiments with the smoke levels developed in the small-scale tests. The results of this ranking are shown in Table 10.

The SPI/UL report notes that the results of the small-scale tests reflect the trend of the results