Depth of Calcination Measurement In Fire Origin Analysis

Patrick M. Kennedy, CFEI, CFPS
Ronald L. Hopkins, CFEI, CFPS
Kathryn C. Kennedy, CFEI

January, 2003

Presentation at the
Fire and Materials 2003
8th International Conference and Exhibition
San Francisco, California
January 28, 2003

DEPTH OF CALCINATION MEASUREMENT IN FIRE ORIGIN ANALYSIS

Patrick M. Kennedy, CFEI
Principal Expert, Fire and Explosion Analyst
John A. Kennedy and Associates, USA
&
Kathryn C. Kennedy, CFEI
Staff Expert, Fire and Explosion Analyst
John A. Kennedy and Associates, USA
&
Ronald L. Hopkins, CFEI
Associate Professor, Fire and Safety Engineering Technology Program
Eastern Kentucky University, USA

ABSTRACT

This is a report on a research project into the practical use of measurements of depth of calcination of room-fire exposed gypsum wallboard, under actual fire scene investigation conditions, to discover and illustrate movement and intensity fire patterns for fire origin determination. The work builds on the previously published research of Posey and Posey, 1983; McGraw and Mowrer, 1999; Mowrer, 2000; and Schroeder and Williamson, 2000 and the procedures outlined in NFPA National Fire Codes component document NFPA 921-2001, *Guide for Fire and Explosion Investigations*, sections 4.12 through 4.12.4.

This research project was performed in conjunction with the 2002 National Advanced Fire, Explosion, and Arson Investigation Training Program cosponsored by the National Association of Fire Investigators (NAFI), the Eastern Kentucky University Fire and Safety Engineering Technology Program (EKU), and the National Fire Protection Association (NFPA).

The research was designed to illustrate and, if appropriate, support the system for measuring depth of calcination on fire exposed vertical gypsum wallboard and used in fire patterns analysis as recommended in NFPA 921.

The tests and data collection were conducted in March 2002 on full-scale room fire evolutions, using ten fire investigators of widely varying experience, from novices to full time professionals, to make and record depth of calcination measurements with no previous knowledge of the actual origins of the test fires.

Additional supplemental laboratory bench testing was conducted as background research into the loss of density of gypsum wallboard from heat exposure at the Forensic Fire Science and Technology Laboratories of John A. Kennedy and Associates.

Research test results were good, providing accurate and reproducible fire movement analysis and supporting the calcination measurement techniques, systems, and tools advocated by NFPA 921. Collected data was comparable among participants with widely varied fire investigation experience and after only minimal instruction and practice in the calcination depth measurement techniques and tools.

INTRODUCTION

National Fire Code (US) component document NFPA 921-2001 *Guide for Fire and Explosion Investigations* is the current "state-of-the-art" standard for fire analysis in the United States. Within its provisions for fire origin determination through fire patterns analysis are procedures for measuring the depth of calcination on gypsum wallboard (GWB) structural lining materials.[1]

Gypsum Wallboard (GWB)

GWB is a common structural lining material consisting of a core of gypsum (calcium sulfate dihydrate) sandwiched between two paper facers.[2]

Calcination is a chemical and physical change in the nature of common GWB produced by heating to temperatures in excess of 80°C (176°F.). This calcination can be defined as: driving out of volatiles (almost exclusively water) from the gypsum component of GWB, in essence, dehydration.[3] When heated above 80°C, approximately 75% of the chemically bound water is driven off.[4] A chemical change in the nature of the gypsum also occurs during the heating process. The calcium sulfate dihydrate ($CaSO_4 \cdot 2H_2O$) becomes calcium sulfate hemihydrate ($CaSO_4 \cdot 1/2H_2O + 1.5H_2O$) at about 100°C (212°F.) and then anhydrous calcium sulfate ($CaSO_4 + 1.5H_2O$) at about 180°C (356°F.).[5]

Significant mass loss and a corresponding decrease in density occur within the calcined portion of the GWB during the calcination process.[6] (This loss of mass and density was re-confirmed in the laboratory bench testing conducted in connection with this research project.)

GWB Calcination Studies in Fire Investigations

The earliest published research into the use of GWB calcination in fire investigations was published by Posey and Posey in 1983.[7] The first edition of NFPA 921 (1992) cites calcination analysis for origin determination in its section 4-12, as does the 1997 United States Fire Administration (USFA) *Fire Burn Pattern Tests* report.[8]

In NFPA 921-2001 the suggested methods for determining depth of calcination are by "…use a visual observation of cross-sections or a probe survey."[9]

The research project reported here was designed to investigate whether practical and scientific validation for the traditionally used "probe survey" method could be found and to compare that method to the less often utilized and more cumbersome, visual cross-section method.

"Probe survey" methods have been in use successfully by professional fire investigators for both calcination and "depth of char" analyses since the 1950's.[10] Similar to its use in depth of char analysis, it is this difference in density between the calcined and original portions of the GWB that is measured using the "probe survey" method. In general, the "probe" method consists of using a calibrated probe caliper-like device to determine the depth of heat treatment to structural lining surfaces, particularly GWB and charred wood. The instrument is inserted perpendicularly into the surface of the heat-treated material, and by feeling the difference in resistance (density) between the pyrolized and non-pyrolized cross-sections, the relative amount of heat treatment is noted.[11] Comparing the relative depths of a series of measurements tells the investigator which points of measurement were more heat treated than others, with the deeper measurements being closer to a single source of heating.

Visual observations of subtle color changes in individually cut cross-sections of the GWB are an alternate method of discerning the relative changes (calcination).[12] But the cross-sectioning method has inherent procedural drawbacks to the practical fire investigation. It is considerably more labor intensive, time consuming, and involves perception of sometimes indistinct color changes frequently made more indistinct by the actual process of cutting the cross-section samples under field conditions, or made more confusing by the presence of impregnated smoke staining in

the gypsum from the burning paper backing.
Practical experience and the research results of this study have concluded that the "probe survey" method, while encompassing some of the same subjective interpretations as the "cross-sectioning" method, is faster, more practical, and considerably less time consuming and labor intensive. In addition, the "probe" method does less destruction to the evidentiary values of the heat-treated surface. This leaves the evidence in place to be available for subsequent investigations and lessens the possibility of complaints of spoliation of evidence. The analytical results of the two methods are statistically comparable.

THE RESEARCH PROJECT

It is important to note that in terms of identifying fire movement patterns for fire origin or fire spread determination, the actual measured depth of calcination itself is not of primary concern. Rather, it is the relative changes, increase or decrease in depth of calcination on GWB, which the fire investigator uses in his or her analysis that is of importance. This being the case, what the actual depth of calcination measurements are is of relatively little import. In their studies, McGraw, Mowrer, Schroeder and Williamson were investigating the links between depth of calcination and flux-time relationships, not fire pattern geometry. While the previously conducted research and testing formed an excellent basis for understanding calcination caused by room fires, there was no specific published research on the use and reliability of the "probe survey" method.

To this end, this research project endeavored to explore whether the "probe survey" method of calcination measurement produced sufficiently reliable results to be effectively employed in fire movement pattern recognition. In planning the research seven key questions were posed:

- How does the difference in measurements made by different individuals affect the fire pattern analysis?
- How does the relative skill and experience levels of the investigators making the measurements affect the outcome?
- What are the quantitative differences between measurements taken with a probe device compared to visual cross-section examination and measurement?
- How does the difference in the "probe method" and the "cross-section visual method" affect the outcome?
- How do the differences in the actual types of measuring devices affect the outcome?
- What kind of training is required before an investigator can take effective measurements?
- Are the overall depths of calcination analysis results accurate and reproducible using the "probe method?"

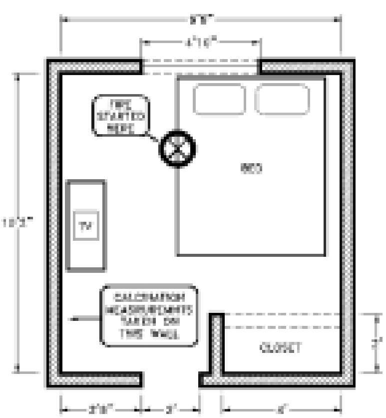
The Test Facilities

Full-scale testing was conducted at the Ashland Fire Safety facility on the campus of Eastern Kentucky University in conjunction with the *2002 National Advanced Fire, Arson, and Explosion Investigation Training Program*, co-sponsored by NFPA, NAFI, and Eastern Kentucky University's Fire and Safety Engineering Technology Program. Two full-scale test rooms were constructed utilizing 2x4 wooden studs on 16" centers, with walls and ceilings covered with ½ inch regular grade GWB connected directly to the studs with drywall screws. The rooms had standard floor coverings and were furnished as a typical bedroom with closet and a living room adjoining a hallway respectively.

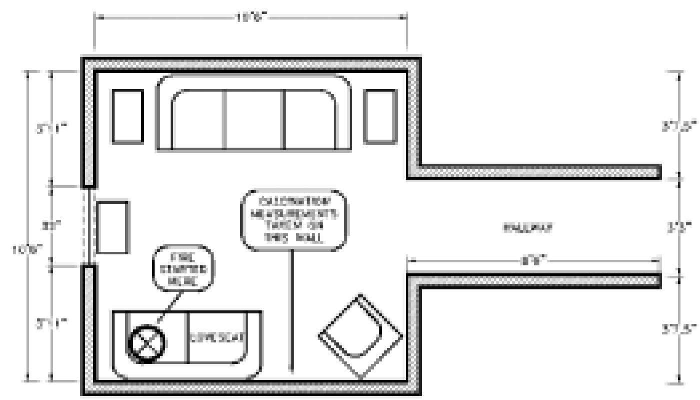
Bedroom Test Room

The bedroom test room was 9’6” x 10’2” with an 8’ ceiling. There was an open 6’6” x 2’ doorway to the exterior at the left side of the front wall, and a small 4’ x 2’ open closet on the front wall adjacent to the door. The flooring was 12” x 12” vinyl floor tiles. There was a closed 4’10” wide x 3’ high double-hung window 43” above the floor in the center of the wall opposite the door and closet. Three standard duplex electrical outlets were installed in the walls, but were not energized.

The bedroom was furnished with a standard 6’ x 5’ metal bed frame, box spring and foam mattress, made up with cotton sheets, acrylic blanket and pillows. A small chest of drawers with a TV on top was placed on a sidewall opposite the bed. The closet contained clothes hung on wire hangers and a plastic laundry basket filled with clothing on the floor. An un-accelerated fire was ignited by lighting the bottom edge of the bedclothes on the left side of the bed approximately 2.5 feet from the head with an open flame.



1. Bedroom Test Room



2. Living Room Test Room

Living Room Test Room

The living room was part of a completely separate two-room test facility. It was 10’6” square with an 8’ ceiling. There was a closed 32” wide, 50” tall double hung window located in the center of the rear wall, 32” above the floor. In the center of the opposite (front) wall there was the opening of a 3’3’ wide, 80” high doorway leading to an 8’6” long hallway that served as the entrance. The front end of the hallway was open to the exterior. There was no door. The floor was carpeted.

The living room was furnished with an upholstered loveseat in the rear left corner along the left wall, a small wooden cabinet under the window, a matching upholstered couch centered on the right wall, flanked by wooden end tables, the front end table held a un-energized typical home coffee maker, and a wooden framed, upholstered cushioned chair was in the front left corner. An un-accelerated fire was set on the seat of the loveseat at the rear, left corner with an open flame applied to newspapers.

The Testing Personnel

Volunteers were sought from the registrants and instructors at the 2002 National Advanced Fire, Explosion, and Arson Investigation Training Program. Five two-person teams were utilized to produce the depth of calcination measurements. The team members alternated as measurement-takers and data-recorders. Included in the participants were individuals who had never before taken calcination probe measurements as well as those who had taken such measurements regularly as parts of actual fire investigations.

The skill and experience levels of the individual team members ranged from complete fire investigation novices (university fire science students) to full-time professional fire investigators with many years of experience (including the senior-most experienced fire analyst in the profession), university-level professors of fire science, fire service investigators (including the senior fire investigator of the London Fire Brigade), law enforcement fire investigators, and private sector investigators and engineers. The formal education levels of the participants ranged from high school graduates to those holding graduate degrees.

The Testing Protocol

The testing protocol began with some preliminary calcination measurement instruction for the testing participants before their taking of the actual research project measurements. A small ¼ scale room test fire was conducted and the testing participants were instructed and allowed to practice taking probe depth of calcination measurements on the GWB ceiling of the test chamber with each of the probe devices.

Each test room fire was ignited with an open flame, without the use of accelerants, allowed to burn through flashover and full room involvement until the fires reached a decay stage. The fires were then extinguished with water using a single 1½-inch hose line equipped with a "task force" nozzle set at a moderately wide spray pattern. Firefighters were admonished to do as little direct damage to the GWB lining materials as practicable.

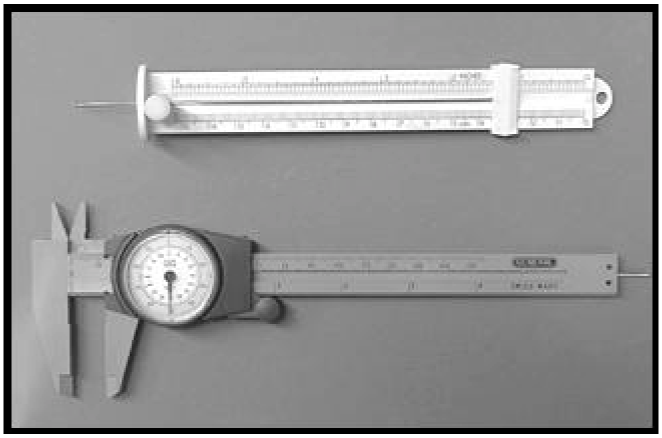
After being allowed to cool down, the subject walls of the two test facilities were marked with a chalk-line grid of one-foot vertical and horizontal squares. Testing participant teams were instructed to have one team member make depth of calcination measurements at the one-foot intersecting intervals of the grid and the second team member record the measurements. The team members then switched roles and repeated the process. Standard grid report forms were produced and issued to the participant teams so that the locations and depths of measurements would be reported in a manner comparable for each set of readings. In order to produce a "blind" in the data collection, team members were purposely not informed of the actual points of origin of the set fires and were not supervised in their actual measurement taking or notation beyond the preliminary instructional session. Each team conducted such measurements on both of the test facilities.

The Test Probes

Measurements were made with one or the other of the two types of probe devices as recommended in NFPA 921-2001[1]

Depth Gauge – A probe depth gauge marketed for measuring the depth of sprayed-on thermal insulation. It has a circular cross-section steel probe of 0.127 cm (0.05") diameter with a slightly chiseled tip. It records depth measurements in either 1/16" or 0.1 mm increments.

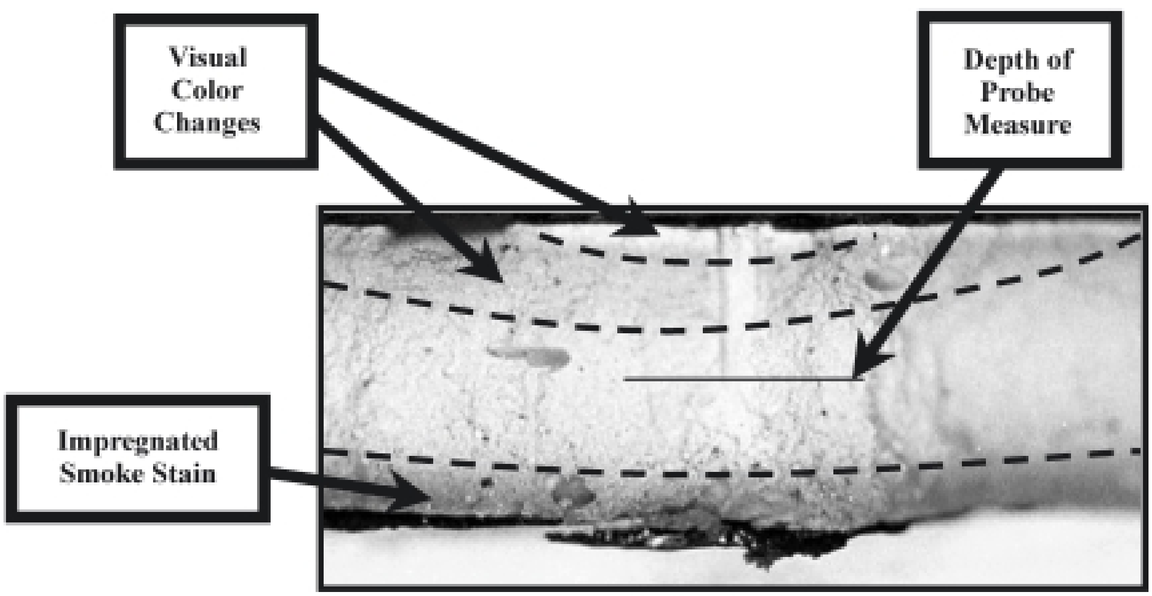
Dial Caliper – A relatively inexpensive, plastic body, dial caliper with a circular cross-section steel probe of 0.178 cm (0.07") diameter and a flat circular cross-section tip. It records measurements in 0.01" or 1/64" increments. It should be noted that more expensive dial calipers tend to be equipped with larger square or rectangular cross-section probes that are less suitable for insertion into the calcined GWP.



3. Depth Gauge and Dial Caliper[14]

Laboratory Bench Tests

To supplement the field measurements portion of the research some laboratory tests were conducted into the change in density of GWB when heated. Several 4" square samples of regular ½" GWB were prepared. The samples were conditioned for several days at approximately 72°F. and 50% relative humidity. Each sample was weighed and then subjected to the same standard flame source for varying times. The standard flame source was a Fisher burner adjusted to produce a 12", premixed propane flame. Each sample was suspended on a ring stand 4" above the burner. After air-cooling the samples were weighed again, probe tested for calcination depth and then cross-sectioned and the visual color differences were measured. One sample was weighed and subjected to a 500C (932°F.) temperature in a muffle furnace for two hours to produce total calcination. After air-cooling the fully calcined sample was weighed again.

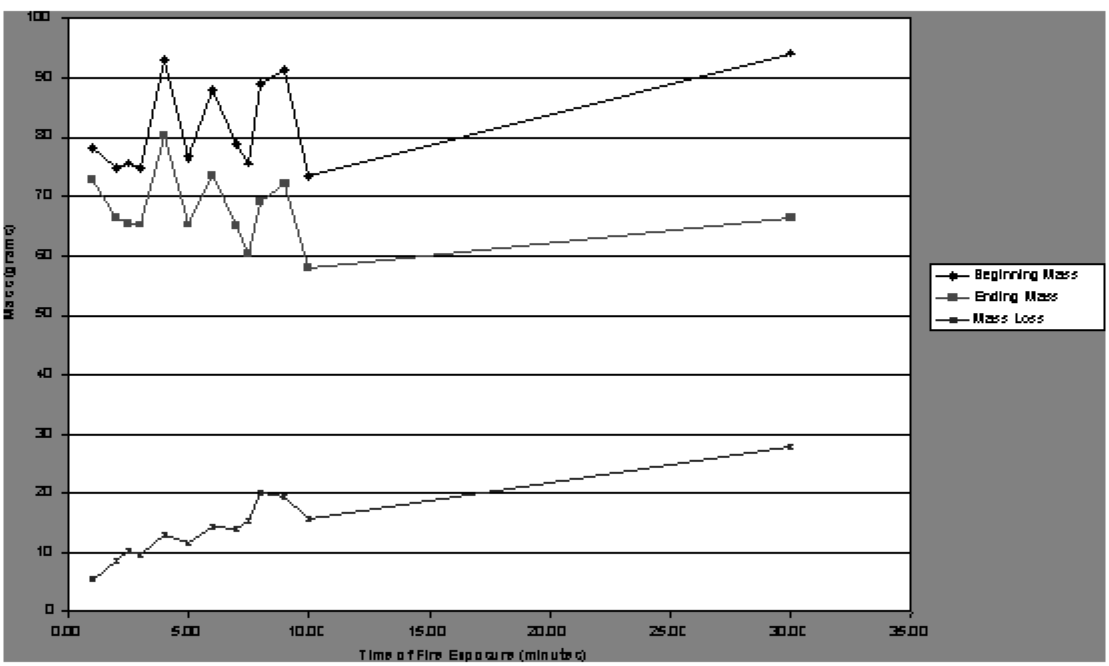


4. Cross-Section of ½" GWB Sample from Bench Tests

Sample	Time in minutes	Initial Mass	Ending Mass	Probe Measurement	Visual Measurement	Mass Loss
E	1.00	78.1g	72.8g	**0.13"**	**0.12"**	5.3g
H	2.00	74.9g	66.3g	**0.25"**	**0.15"**	8.6g
C	2.50	75.6g	65.3g	**0.23"**	**0.16"**	10.3g
I	3.00	74.8g	65.2g	**0.28"**	**0.18"**	9.6g
G	4.00	93.1g	80.2g	**0.33"**	**0.23"**	12.9g
B	5.00	76.6g	65.2g	**0.37"**	**0.24"**	11.4g
F	6.00	87.8g	73.6g	**0.42"**	**0.25"**	14.2g
J	7.00	78.8g	64.9g	**0.42"**	**0.31"**	13.9g
D	7.50	75.6g	60.4g	**0.32"**	**0.30"**	15.2g
K	8.00	89.0g	69.1g	**0.42"**	**0.24"**	19.9g
L	9.00	91.4g	72.0g	**0.44"**	**0.35"**	19.4g
A	10.00	73.3g	57.8g	**0.50"**	**0.27"**	15.5g
M*	120.00	94.2g	66.4g	**-**	**-**	27.8g

* Heated to 500 C in Muffle Furnace for two hours

5. Table of Bench Tests Results



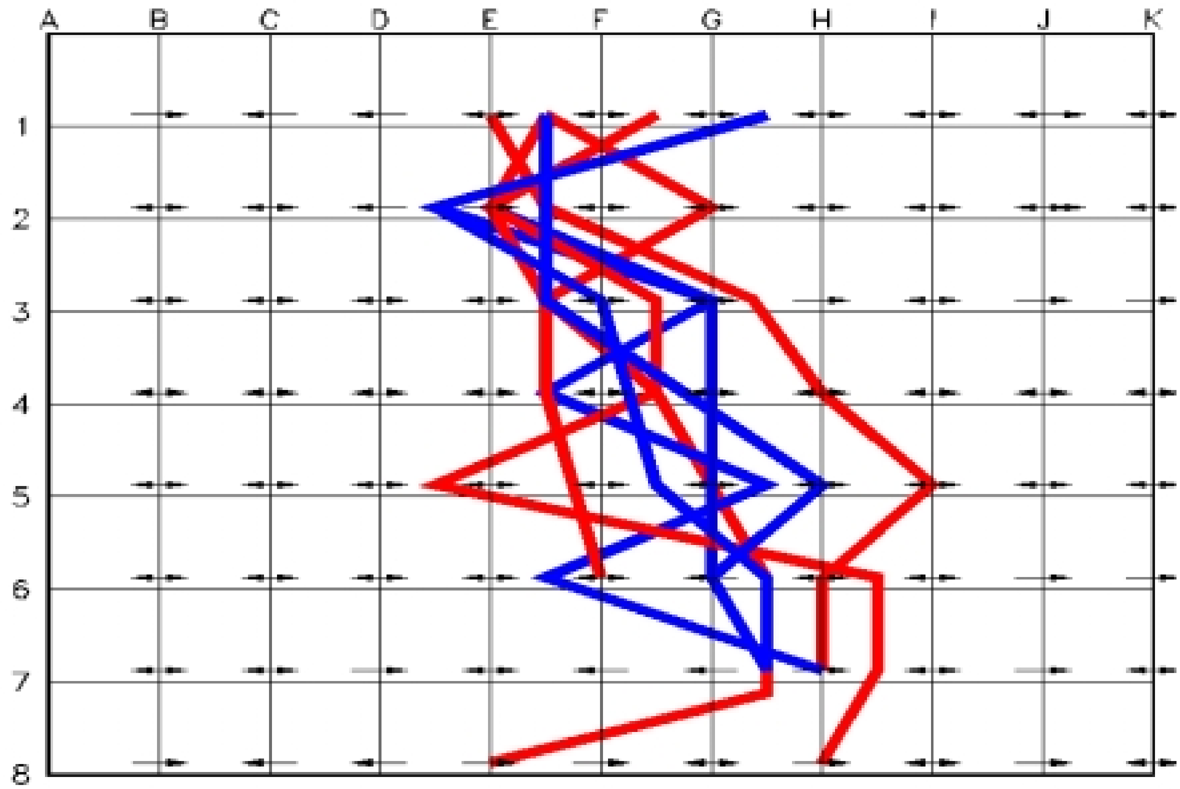
6. Mass Loss in Bench Tests

RESULTS OF THE RESEARCH

The collected data was tabulated and analyzed by comparing the actual depth measurements, lateral changes in depth, and averages of these values. The results were also tabulated in groups by the type of probe instrument used and by which of the two test rooms were being measured.

Difference in Measurements Made by Different Individuals

Though the individual depth of calcination measurements varied somewhat from individual to individual, the actual relative differences between adjoining measurements were largely similar.



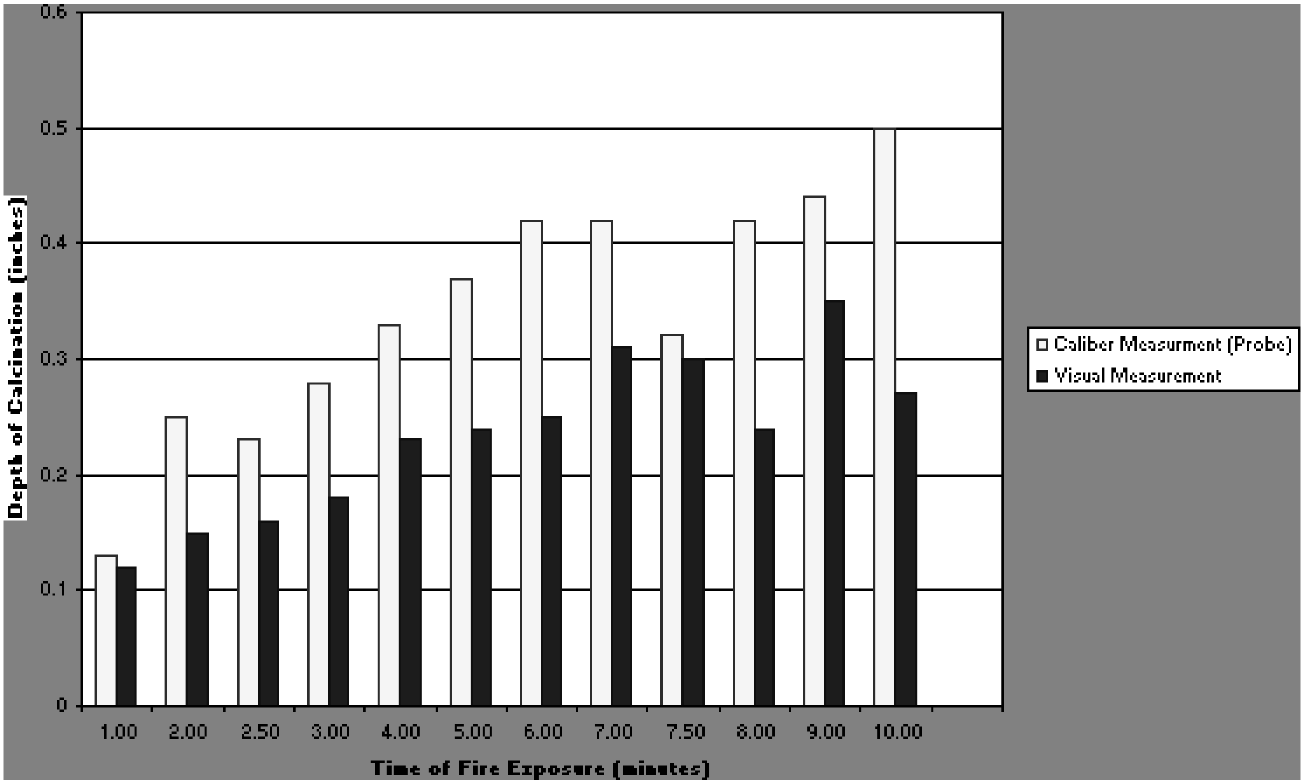
7. Mid-Point of Measurements of Bed Room with both Depth Gauge and Caliper

Relative Skill and Experience Levels of Investigators

The varying skill and experience levels of the participants did not affect the overall outcome of the fire patterns analyses. There was, however, a noticeable difference in the quality of the recording of the measurements. Less experienced investigators tended to be less precise in their work. The relative abilities of the participants to accurately read or transfer the actual measurements to the notes was problematical. For example, some participants consistently recorded measurements with incorrectly assigned decimal points, ("5" when the actual reading should have been "0.5"). But since these errors were obvious, and the errors were consistent on any given set of notes, the relative changes in calcination depth across a particular wall were properly reported and could be used in the overall analysis.

Quantitative and Qualitative Differences Between Measurements Taken with a Probe Device or Visual Cross-Section Examination

This aspect was studied during the laboratory bench tests into the mass loss and density change rates. Observed visual color changes in the test samples were of consistently less depth than the probe measurements. However the relative differences between measured depths per total flux were consistent for both types of measurements. Therefore, though the quantitative differences did exist, the qualitative analyses were unaffected.



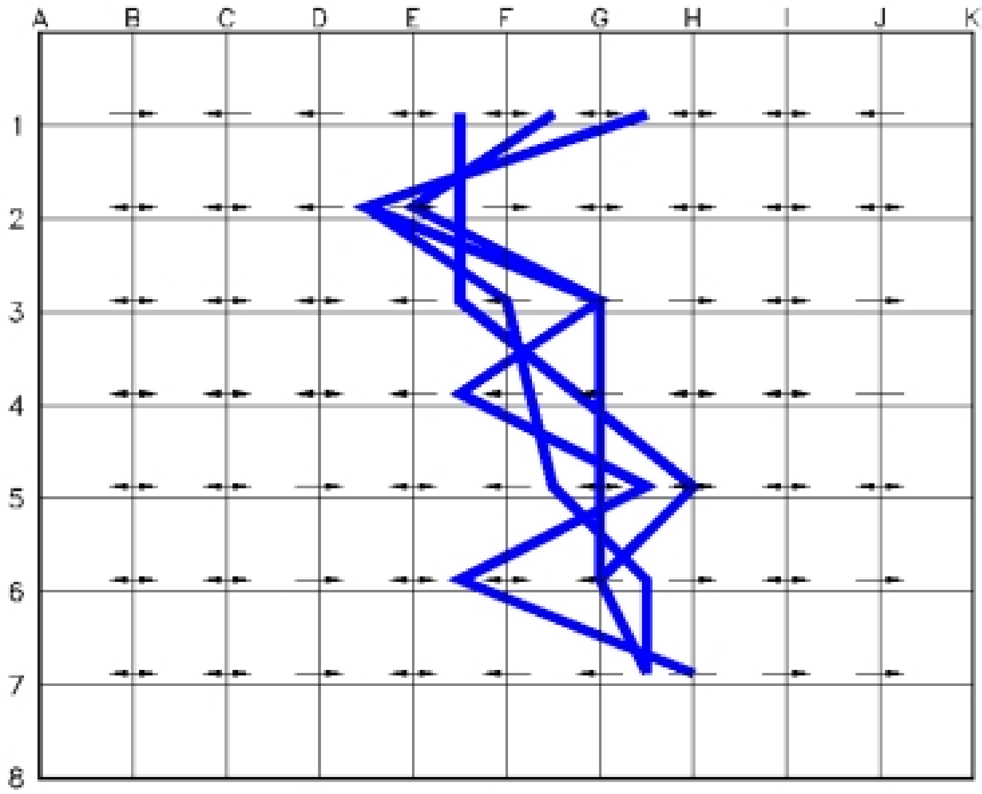
8. Probe vs. Visual Measurements

Differences in the Types of Probe Measuring Devices

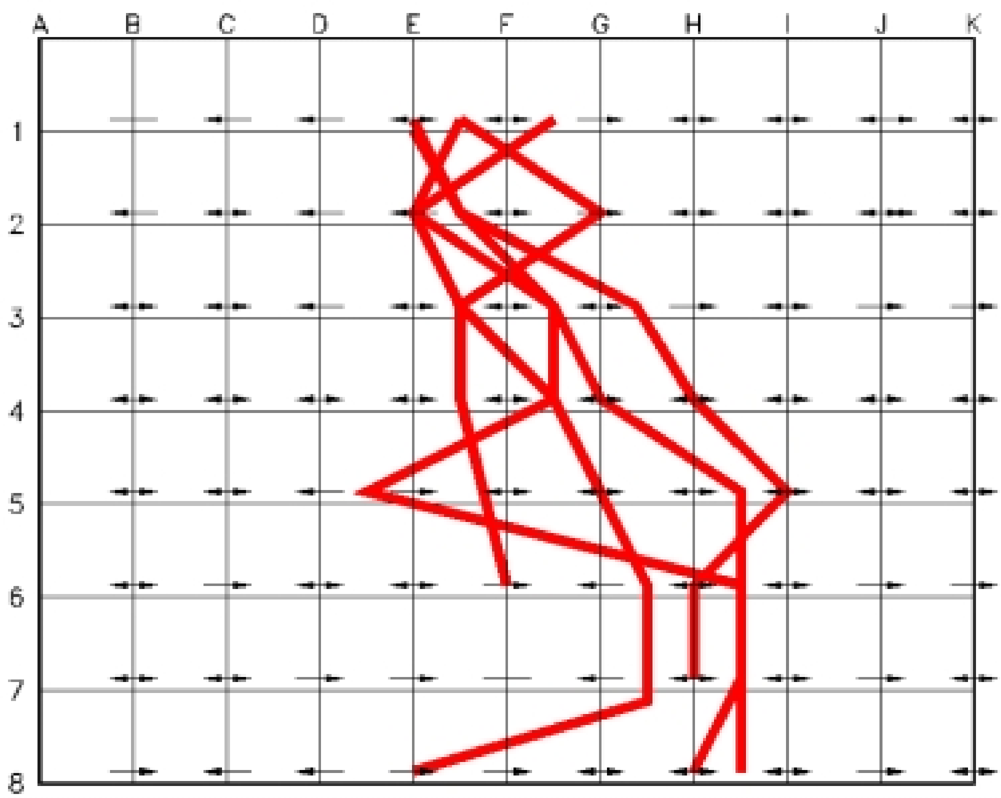
Either of the two instruments, depth gauge or dial caliper, produced acceptable measurements, both in ease of use and accuracy. Measurements in increments smaller than 0.01” produce an incremental precision too small for practical field conditions’ evaluations.

Comparisons of the individual tests data records indicate that the dial caliper instrument was easier to read, especially by those not familiar with the two instruments, tended to produce fewer “questionable” notations of depth measurements and thereby, within the parameters of the research project, produced somewhat more reliable information than the depth gauge. In addition, because of the versatility of the various measuring modes allowed by the dial caliper, it is more useful overall to the fire investigator for other types of measurements that might be needed at a fire scene.

However, the depth gauge did have two useful features that the dial caliper did not. A locking screw for the probe when used by the participant tended to prevent an inadvertent change in the measurement when the probe was pulled out of the GWB and then read. The depth gauge also had a 1.13” diameter circular platform just above its probe that helped the participant be sure of making depth measurements more nearly perpendicular to the wall surface.



9. Mid-Point of Measurements of Bed Room with Dial Caliper



10. Mid-Point of Measurements of Bed Room with Depth Gauge

Training Required for Effective Measurements

Each of the test participants was given about fifteen minutes of instruction and practice before taking the actual research project measurements. This proved to be adequate. Clearly, the main problems encountered were in giving the measurement takers enough actual hands-on practice to be consistent in the application of pressure when pushing the probe into the GWB. Getting used to physically manipulating the two different types of probes and being careful to accurately read and record the measurements under field conditions are also considerations which clearly require at least some training and practice.

Accuracy and Reproducibility Using the "Probe Method"

The use of participants with widely varying skill and experience levels, two different types of measuring devices, and two different test rooms did not appear to have changed the overall tests results. Each of the participant's individual results correctly identified the fire movement and spread laterally and vertically along the measured walls from the two separate points of origin. Collectively and on averaging the results, the grouped fire pattern analyses were also consistent with the known points of origin.

SUMMARY OF CONCLUSIONS

1. The "probe survey" method of depth of calcination/fire pattern analysis produces accurate and reproducible analysis results.
2. Though quantitative differences are observed between the "probe survey" and "visual observations of cross-sections" methods, qualitatively they are interchangeable.
3. Findings are comparable between the "probe survey" and "visual observations of cross-sections" methods.
4. Differences in skill and experience levels between individual investigators do not affect the overall depth of calcination analyses results.
5. Only minimal training and practice is required for investigators to glean usable data in the "probe method" of taking depth of calcination measurements.

REFERENCE LIST

NFPA 921 *Guide for Fire and Explosion Investigations*, §4.12 – 4.12.4, National Fire Protection Association Quincy, MA, SA. 2001ı

[2] McGraw, J. Robert Jr. and Mowrer, Frederick W., Flammability of Painted Gypsum Wallboard subjected to fire Heat Fluxes, *nterflam '99*, Interscience Communications Ltd., London, 1999ı

[3] Schroeder, R. A. and Williamson, R. B., *Post-fire Analysis of Construction Materials-Gypsum Wallboard*, Fire and Materials, John Wiley & Sons, Ltd., 2000ı

[4] ibidı

[5] Mowrer, *Calcination of Gypsum Wallboard in Fire*, NFPA World Fire Safety Congress, Anaheim, California, May 14, 2001ı

[6] ibid.ı

[7] Posey, James E. and Posey, Eleanor P., *Using Calcination of Gypsum Wallboard to Reveal Burn Patterns*, The Fire and rson Investigator, IAAI, St. Louis, MO, 1983ı

[8] Kennedy, Patrick M. and Shanley, James, H., Jr.. "USFA Fire Burn Pattern Tests," United States Fire Administration, mmitsburg, MD, FA 178, July 1997.ı

[9] NFPA 921, §4.12.4ı

[10] Kennedy, John and Kennedy, Patrick M., Fire and Arson Investigation, Investigations Institute, Chicago, IL, 1962ı

[11] NFPA 921, § 4.5.3.3ı

[12] ibid., Posey and Posey