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Effects of Vapor-Based Decontamination Systems on Selected Building Interior Materials: Vaporized Hydrogen Peroxide

Office of Research and Development
National Homeland Security Research Center

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Disclaimer

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List of Acronyms

APG	Aberdeen Proving Grounds
ASTM	American Society for Testing and Materials
CB	chemical and biological
ClO_2	chlorine dioxide
CoC	chain-of-custody
CT	concentration time
CW	chemical warfare
doc	documentation
DS	Decontamination Sciences
ECBC	Edgewood Chemical and Biological Center
EPA	U.S. Environmental Protection Agency
GSA	General Services Administration
H_2O_2	hydrogen peroxide
hr or hrs	hour or hours
IAG	Interagency Agreement
IAW	in accordance with
ID	Gant Chart representation for task number (on Gant Chart only)
IOP	internal operating procedure
ISO 17025	International Standardization Organization Standard 17025 on Laboratory Quality Procedures
MSDS	Material Safety Data Sheets
NHSRC	National Homeland Security Research Center
QA	quality assurance
QAPP	Quality Assurance Project Plan (QAPP)
QMP	Quality Management Plan
R&D	Research and Development
RDECOM	Research, Development, and Engineering Command (formerly SBCCOM)
RH	relative humidity
SOPs	standing operating procedures ("standard" may also be used in place of "standing" with the same meaning)
TICs	toxic industrial chemicals
TIMs	toxic industrial materials
UL	Underwriters Laboratories
V	volt
VHP®, VHP	reference to Steris' registered "vaporized hydrogen peroxide" procedure

Coupon-Specific Coding

“W”	bare wood
“R”	carpet
“T”	ceiling suspension tile
“G”	latex-painted gypsum wallboard
“S”	painted structural A572 steel
“C”	unpainted concrete cinder block
“A”	aluminum coupons
“D”	copper coupons
“F”	steel coupons

1.0 Background

The material compatibility studies were designed to determine how decontaminant vapors impact building materials within an enclosed building interior space. Since building interiors may contain large surfaces composed of complex materials and electrical components such as circuit breakers, data are needed to determine how such materials are affected by exposure to the vapor. Vaporized hydrogen peroxide (VHP®) and chlorine dioxide (ClO_2) were selected for study since these decontamination technologies have been used to decontaminate indoor surfaces contaminated by anthrax and show potential for use in decontaminating indoor surfaces contaminated by chemical agents. Representative building interior materials were tested including unpainted concrete cinder block, standard stud lumber (2″x 4″ fir), latex-painted ½-inch gypsum wallboard, ceiling suspension tile, painted structural steel, and carpet. The physical properties of the building materials were measured using American Society for Testing and Materials (ASTM) test methods. The material compatibility studies also investigated electrical breakers, using Underwriters Laboratories (UL) test methods. Specialized chemical testing was conducted to determine whether chemical changes occurred in select building materials. In addition, visual appearance was documented. This report contains the results for the VHP-exposed coupon material compatibility tests. The ClO_2 results are documented in a separate report.

2.0 Summary of Conclusions

VHP-exposed building materials showed no change in appearance or in integrity compared to nonexposed samples. The samples were evaluated for outliers using the Dixon's Q-Test in accordance with (IAW) ASTM Method E 178 and for statistically demonstrated differences using the Welch's T-Test.

- **Painted Structural Steel:** The fumigated structural steel coupons show some minor changes (1–3%) in tensile strength when compared to the control coupons. All samples were above the specified tensile strength requirements of the ASTM test (by 20% or more). There is no obvious change in the potential for failure of the steel after fumigation using VHP.
- **Gypsum Wallboard:** Exposure to VHP makes gypsum wallboard more resistant to penetration by a nail.
- **Ceiling Tile:** Exposure to VHP causes a small increase in the breaking force required for the ceiling tile coupons.
- **Carpet:** Exposure to VHP appears to slightly increase the force required to pull the carpet tuft bind.
- **Concrete Cinder Block:** The fumigated concrete cinder block samples did not exhibit any changes from the control samples. There is no evidence to indicate that fumigation with VHP has any effect on cinder blocks.
- **Wood:** The fumigated pine furring strips, prepared from the stud lumber, exhibit no statistically detectable changes from the control samples, though a very minor trend of increasing maximum force and increasing time to break was observed.
- **Circuit Breaker:** Exposure to VHP presents a conflicting picture of the effects on circuit breakers. Under the 60-amp challenge, exposed circuit breakers trip more rapidly than the controls. Under the 30-amp challenge, the circuit breakers trip more slowly than the controls. Either situation could present a problem to the user. Failure criteria must be established to determine whether the changes observed in this test present an acceptable response.
- **Visual Inspection:** No differences are observed for any of the coupons after VHP exposure and aging compared to before VHP exposure.

3.0 Introduction

To address homeland security needs for decontamination, the U.S. Environmental Protection Agency (EPA) established an Interagency Agreement with the U.S. Army Edgewood Chemical and Biological Center (ECBC) to take advantage of ECBC's extensive expertise and specialized research facilities for the decontamination of surfaces contaminated with chemical and biological (CB) warfare agents. The National Homeland Security Research Center (NHSRC) formed a collaboration with ECBC in a mutual leveraging of resources, expanding upon ECBC's ongoing programs in CB decontamination to more completely address the parameters of particular concern for decontamination of indoor surfaces in buildings following a terrorist attack using CB agents, or toxic industrial chemicals (TICs) or materials (TIMs). In the context of decontamination, the contaminants of interest are those that can persist on indoor surfaces, leading to continuing chance of exposure long after the contamination occurs. VHP® and ClO_2 are decontamination technologies that have been used to decontaminate indoor surfaces contaminated with anthrax spores and show potential for use in decontaminating indoor surfaces contaminated by some chemical agents. This program is specifically focused on decontamination of the building environment, for purposes of restoring a public building to a usable state after a terrorist contamination episode. Systematic testing of decontamination technologies generates objective performance data so building and facility managers, first responders, groups responsible for building decontamination, and other technology buyers and users can make informed purchase and application decisions.

Since building interiors may contain large surfaces composed of complex materials, material compatibility studies were designed to determine how the decontaminant vapors impact building materials within an enclosed building interior space. The objective of this study was to conduct laboratory test procedures to determine to what degree building materials were affected by decontamination using VHP® and ClO_2. The building interior materials used for testing were a subset of the variety of structural, decorative, and functional materials common to commercial office buildings regardless of architectural style and age. The building materials studied encompassed a variety of material compositions and porosities; they included unpainted concrete cinder block, standard stud lumber (2″x 4″ fir, type-II), latex-painted ½-inch gypsum wallboard, acoustical ceiling suspension tile, primer-painted structural steel, and carpet. The material compatibility studies also investigated material(s) related to electrical breaker connections. The physical appearance was documented by visual inspection of the test material. The physical properties of the building materials were measured using standardized ASTM and UL test methods.

The VHP® technology developed by Steris (EPA registration #58779-4) has been in use for more than a decade. The VHP fumigant was initially used to sterilize pharmaceutical processing equipment and clean rooms.[1,2] In response to the anthrax attacks of October 2001, Steris adapted its VHP technology to perform the decontamination of two U.S. government facilities, the General Services Administration (GSA) Building 410 at Anacostia Naval Base, Washington, DC, and the U.S. Department of State SA-32 Sterling VA mail center.

Decontamination of an interior space using VHP is a four-phase process involving preparation of the building interior air (dehumidification), achieving a steady-state decontaminant level (conditioning), performing the decontamination, and then aerating for safe reentry (Figure 3.1).[3]

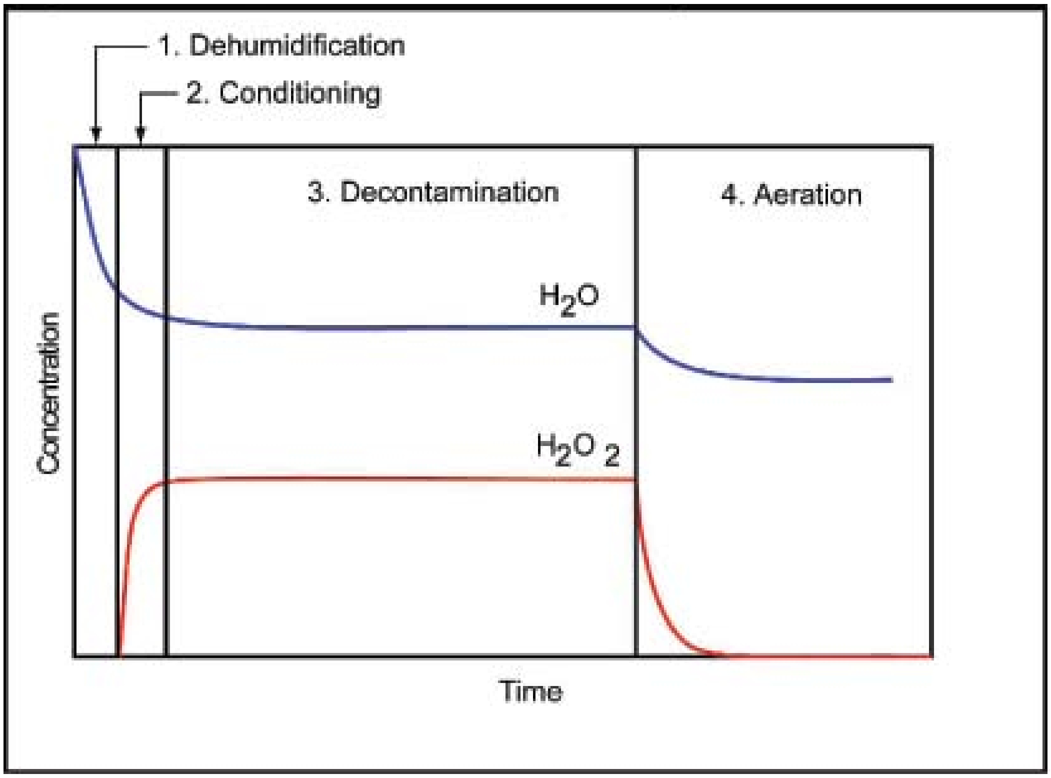
Dehumidification: Hydrogen peroxide vapor can co-condense with water vapor producing an undesired condensate high in hydrogen peroxide. High relative humidity (RH) and/or cold temperatures are likely to permit condensation, but it can be prevented by circulating dry, heated air through the interior prior to injection of the hydrogen peroxide vapor. The target humidity level is determined by the concentration of vapor to be injected and the desired steady-state concentration for the decontamination. The lower relative humidity permits a higher concentration of hydrogen peroxide without reaching a saturation point. For this study, the maximum RH at start-of-run (prior to introducing decontaminant) was 30%.

Conditioning: During the conditioning phase, the injection of hydrogen peroxide vapor is initiated at a rapid rate to achieve the desired chamber concentration set point without condensation. Once the target concentration is achieved, the injection rate is lowered to maintain the set-point concentration.

Decontamination: Decontamination is a timed process dependent on the hydrogen peroxide vapor concentration. In actual building applications, a decontamination timer counts down from the preset decontamination time. If the concentrations or temperature values fall below the set point, the timer stops. This ensures that during the decontamination phase the building interior is exposed to at least the minimum decontamination conditions for the desired exposure time. For this laboratory-scale study, the enclosure VHP concentration was maintained within the target concentration range.

Aeration: After completion of the decontamination phase, the hydrogen peroxide injection is terminated. Air is introduced into the chamber and displaces the hydrogen peroxide. The space is monitored until the hydrogen peroxide concentration falls to a safe level for coupon removal.

Figure 3.1: The Steris VHP® Decontamination Cycle



4.0 Experimental Method

Material compatibility testing was conducted in compliance with the Quality Assurance Project and Work Plan[4] developed under the Quality Management Plans[5,6] and EPA E4 quality system requirements.[7–9]

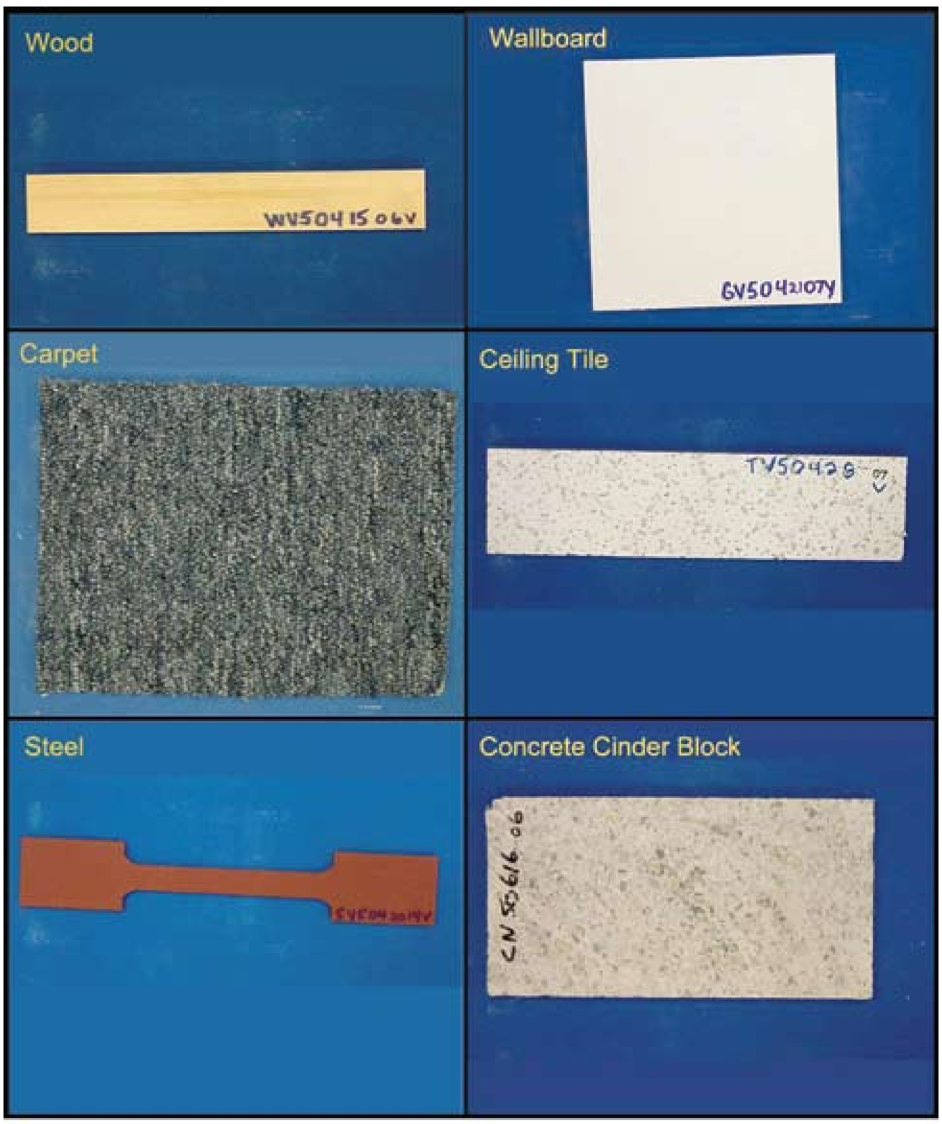
4.1 Coupon Preparation

Test coupons were prepared in accordance with ASTM testing requirements for material compatibility testing. The coupons were cut from stock material IAW the procedure in Appendix B of the QAPP[11], which has been reproduced as Appendix B of this report. Coupons were prepared by obtaining a large enough quantity of material that multiple test samples could be obtained with uniform characteristics (e.g., test coupons were all cut from the interior rather than the edge of a large piece of material). The building materials studied, as well as supplier and coupon dimensions, are provided in Table 4.1 and shown in Figure 4.1.

Chain-of-custody (CoC) cards were used to ensure that the test coupons were traceable throughout all phases of testing. The coupons were measured and visually inspected prior to testing to ensure that they were within the acceptable tolerances (Appendix B) and were not defective and/or damaged. Coupon measurements and visual inspection were recorded on the CoC card. Coupons that were defective, damaged, or not within the allowable size tolerances were discarded. Each coupon was assigned a unique identifier code to match it with the sample, test parameters, and sampling scheme (Appendix A). The code was also recorded on the CoC cards, which followed each sample from exposure testing through material compatibility testing to disposal.

The material compatibility studies also investigated materials related to electrical breaker connections such as intact one-pole circuit breakers (HOM120, 2400 watts, 120/240 volts, 20 amperes).

Figure 4.1: Samples of the Test Coupons



*Coupons are not shown to scale

Table 4.1: Representative Building Interior Materials

Material	Code	Supplier	Length	Width	Thickness
Structural Wood, fir	W	Home Depot	10.0 in	1.5 in	0.5 in
Latex-Painted Gypsum Wallboard	G	Home Depot	6.0 in	6.0 in	0.5 in
Concrete Cinder Block	C	York Supply	4.0 in	8.0 in	1.5 in
Carpet	R	Home Depot	6.0 in	8.0 in	0.0 in
Painted Structural Steel	S	Specialized Metals	12.0 in	2.0 in	0.3 in
			5.3 in	0.8 in	0.3 in
Ceiling Suspension Tile, Acoustical	T	Home Depot	12.0 in	3.0 in	0.6 in

4.2 Coupon Exposure: Wood, Wallboard, Ceiling Tile, Steel, Carpet, and Concrete Cinder Block

The process for exposing the building material samples to VHP and results for the material demand study are documented in a separate report titled "Material Demand Studies: Materials Sorption of Vaporous Hydrogen Peroxide," by Lawrence Procell et. al. This testing followed the operating procedures specific to the Steris technology. A brief overview of the exposure process is provided in this section; the material demand report contains the detailed test information and results.

The coupons were placed in the exposure chamber. The RH inside the glove box was regulated below 30% during the dehumidification phase with dry air added as necessary. The temperature during the decontamination phase was kept above the minimum requirement of 30 °C. The vapor generator was operated to maintain the chamber concentration within specified ranges. The full-target concentration was 250-ppm VHP for four hours for a total concentration-time (CT) value of 1000 ppm-hrs. The half-target concentration was 125-ppm VHP for eight hours, also for a total concentration-time (CT) value of 1000 ppm-hrs. Air exchange conditions were chosen to maximize the residence time of the vapor in the chambers, while concurrently minimizing the background vapor decomposition under baseline conditions in the absence of materials. The VHP tests were conducted with a turnover rate of approximately 16 exchanges per hour to compensate for the higher spontaneous decomposition of VHP. Aeration of the chamber was conducted following the decontamination phase (exposure period) and continued until the vapor concentration fell to/below the levels required by the Risk Reduction Office to ensure safe operation for personnel. The coupons remained in the chamber until aeration was complete. The standard measuring range of the VHP monitor is 0 to 10.0 ppm H_2O_2 with a display resolution of 0.1 ppm. Control samples were prepared using the same procedure as the test runs except with only air (no fumigant) through the chamber. Three replicate runs were done for each sample at each condition. The samples were removed from the chamber, marked with unique sample identifier codes, and visually examined.

4.3 Coupon Exposure: Circuit Breakers

Like the building materials discussed in Section 4.2, the circuit breakers (Hom220, Home Depot) were placed in the exposure chamber and exposed to fumigant. After exposure to the decontaminant, the circuit breakers were stored in a fume hood for two days and then placed in storage under load for three months. Each set of circuit breakers was inserted into an electrical box (8 spaces, 16 circuits, 100 amp max from square D, Home Depot # 577-340). The circuit breaker box was wired with 12-gauge, 20-amp wire into the 120-volt outlet. Each circuit breaker was wired in series with an electrical lamp (s513e) with an outlet box (s110e) manufactured by Thomas & Bretts (Home Depot # c214477 and b214426, respectively). The load in each lamp was a Phillips 40-watt light bulb (Philips and Sylvania, Home Depot). Current was applied to the circuits and monitored. At the end of 90 days, the circuit breakers were tested to determine the effect of VHP.

4.4 Visual Inspection

The coupons were visually inspected and digitally photographed upon removal from the chamber. Visual inspection of the coupon surfaces was conducted through side-by-side comparison of the decontaminated test surface and fresh coupons of the same test material. The testing staff looked for changes such as discoloration, blistering, warping, and peeling on the test coupon. After the visual inspection was completed, the coupon custody was transferred to the Material Compatibility Technical Leader for the three-month aging period and material compatibility testing. The coupons were examined again at the time of the material testing and the visual appearance recorded on the data test forms. If the coupon had dramatic changes compared to a fresh coupon, then the coupon was photographed and the photograph was included in the report. Representative photographs of each material type are provided in the report.

4.5 Coupon Aging

The material compatibility studies were conducted using the coupons from the material demand study. The coupons were aged for a minimum of 90 days following exposure to the decontaminant prior to material compatibility testing. The coupons were placed in open containers and stored under ambient conditions. The open container arrangement allowed aging of the coupons in conditions mimicking real-world aging.

4.6 Data Review and Technical Systems Audits

The approved Material Compatibility QAPP specified procedures for the review of data and independent technical system audits. All data were peer reviewed within two weeks of collection. The project quality manager (or designee) was required to audit at least 10% of the data collected. Two technical system audits were performed over the course of testing. A technical system audit is a thorough, systematic, on-site qualitative audit of the facilities, equipment, personnel, training, procedures, record keeping, data validation, data management, and reporting aspects of the system.

4.7 Physical Testing

An Instron Model 5582 was used for the physical property testing. The Instron is a universal testing machine capable of performing tensile, compression, shear, peel, and flexural tests on most materials and components. Each material subsection contains a photograph of the coupon loaded into the test apparatus. The Instron model 5582 specifications are listed in Table 4.2.

4.8 Statistical Analyses

The data from the material compatibility testing phase of the systematic decontamination program were subjected to a statistical analysis to determine whether the differences observed between the various test sets were merely the result of random variations in test data or represented actual differences in the performance of the materials as a result of exposure to fumigation chemicals.

Methods used were from the statistical analysis functions embedded within both the Microsoft Excel software and *Practical Statistics for Analytical Chemists*, by Robert L. Anderson, © 1987, Van Nostrand Reinhold Company.

First, the individual coupon test sets were tested for statistical outliers that could be eliminated from the data. The Dixon's Q-Test for outliers was first used to identify potential outliers within a test group of coupons that had undergone similar treatment (controls, half-target, or full-target exposures). If an outlier was identified in the test group analysis, it was eliminated and the statistics (averages and standard deviations) were recalculated.

Once statistical outliers had been eliminated, the test groups were analyzed to determine whether they were statistically significantly different – that is, to determine whether the treatment with the chosen fumigant had a detectable effect on the sample.

Welch's T-test values were calculated to compare the test groups, and results are reported for the 95% level of confidence. The percent level of confidence reported indicates the confidence that the two sample groups being compared are, in fact, different and represent truly different samples. A 95% level of confidence indicates a 5% chance that the two samples are, in fact, subparts of the same population. If a comparison determines that a sample is significantly different at the X% level of confidence, it is also significantly different at any lower level of confidence.

Detection that a control and exposed sample are statistically different implies that the treatment likely had some detectable effect on the material. Statistically different results do not imply that the material will fail as a result of treatment, unless the material no longer meets specifications. In some cases, measured values may vary by several percent; however, there is no statistically detectable difference. It cannot be assumed that this difference is real unless the difference is statistically detected (e.g., by a Welch's T-test).

4.9 Chemical Testing: FTIR

The effects of decontaminant vapor on the cellulose and other polymers in wood at the molecular level were studied using a diffuse reflectance infrared Fourier transform (DRIFT) technique. Chemical reactions between the decontaminant vapor and the wood (i.e., oxidation and cleaving of the polymer chains) can be evidenced by significant changes in the infrared spectra of the wood. Fourier Transform Infrared Spectroscopy (FTIR) was performed on twelve wood coupons to examine the substructural oxidation effect of VHP and liquid hydrogen peroxide. Results of these tests are provided in Section 13.0.

Table 4.2: Instron Model 5583 Specifications

Load Capacity:	kN	100
	Kgf	10000
Maximum Speed:	mm/min	500
Minimum Speed:	mm/min	0.001
Maximum Force at Full Speed:	kN	75
Maximum Speed at Full Load:	mm/min	250
Return Speed:	mm/min	600
Position Control Resolution:	µm	0.06
Total Crosshead Travel:	mm	1235
Total Vertical Test Space:	mm	1309
Height:	mm	2092
Width:	mm	1300
Depth:	mm	756
Weight:	kg	862

5.0 Post-Fumigation Inspection

The coupons were visually inspected prior to fumigation (pre-fumigation), immediately after fumigation (post-fumigation), and after storage (post-storage) at the time of material testing. Carpet coupons were inspected for any frayed tufts, pulled loops, and other noticeable defects. Concrete coupons were inspected for cracks, chips—particularly at the corners — any raised ridge sections, and other noticeable defects. Steel coupons were inspected for rust, peeling paint, any ridged sections on the small I-beam cross section, and any other noticeable defects. Tile coupons were inspected for crushed corners and edges, and any other noticeable defect. Wallboard coupons were inspected for any damage to the paper section, as well as any other noticeable defects. Wood coupons were inspected for any knots, missing knots, splitting, and other noticeable defects. The post-fumigation and post-storage inspections were compared to the initial (pre-fumigation) inspections. No differences were observed for any of the coupons after VHP exposure and aging compared to before VHP exposure.

6.0
Evaluation of Structural Steel

6.1 Introduction

The effects of VHP on the physical integrity of steel were investigated using the tension test as described in ASTM Test Method A370-03a "Standard Test Methods and Definitions for Mechanical Testing of Steel Products," Sections 5–13. The tension test was used to determine the integrity of steel coupons exposed to vaporous decontaminant compared to unexposed (control) steel coupons.

6.2 Sample Preparation and Testing

The steel samples were removed from storage, visually inspected, and measured. The coupons from chamber positions 1, 4, 7, 10, and 16 were selected for testing in order to obtain representation throughout the test chamber. The samples were used "as is" without any additional preparation. The testing was conducted in accordance with the ASTM Test Method A370-03a. The Instron fixture for the steel test was installed prior to testing. The Instron universal testing machine operation and calibration verification was conducted by suspending a certified weight from the fixture and recording the weight. Three sets of five coupons were tested for each concentration (full-target and half-target) and four sets were tested for the controls (0 ppm). The load required to rupture the steel coupons was measured in Newtons (N). The tensile strength is the maximum tensile stress that a material is capable of sustaining and is calculated by dividing the amount of force required to rupture a specimen by the specimen cross-sectional area. The cross-sectional area for the steel, dog bone shaped coupon is the center width of the coupon multiplied by the center thickness. No precision or bias requirements have been established for this test method. The results for control coupons were compared against the results for decontaminant-exposed coupons. A statistical analysis of the data was conducted to determine whether the decontaminant-exposed steel coupon results were statistically different from the control steel coupon results. A photograph of a representative steel sample before and after testing is provided in Figure 6.1.

Figure 6.1 Photograph-Steel Coupon Test

6.3 Results

The coupons were stored for at least 90 days after fumigation. The actual number of storage days was based on the arrival of the Instron fixtures for testing. The coupons for a particular fumigation were studied after a similar number of days in storage. Values for the load required to rupture the steel coupons, the tensile strength results, and the number of days in storage before testing are provided in Table 6.1.

6.4 Discussion

The steel studied was an A572 Grade 50 high-strength structural steel. The minimum tensile strength requirement is 450 N/mm^2. All coupons met this minimum specification.

A statistical analysis of the test group results was conducted to detect potential statistical outliers (Q-test) and determine whether there were any differences between the control and exposed samples (Welch's T-test). Two test coupons were flagged for having tensile strength values that were outliers within their test sets at the Q=0.99 confidence level; these values are highlighted in orange in Table 6.1. However, within test groups (control samples, half-target concentration samples, and full-target concentration samples), statistical analysis showed that none of the coupons could be eliminated as statistical outliers. Therefore, all values were retained for the statistical analysis.

The average values for the maximum load for the test groups were: 61744 ± 1597 N for the control coupons; 61811 ± 1337 N for the half-target coupons; and 61040 ± 437 N for the full-target coupons. The average values for the tensile strength of the steel coupons were as follows: 555 ± 19 N/mm^2 for the control coupons; 545 ± 23 N/mm^2 for the half-target coupons; and 549 ± 15 N/mm^2 for the full-target coupons.

For both the half-target concentration and full-target concentration samples, the average tensile strengths were slightly lower than the control samples, but all were well over the minimum acceptable value from the ASTM standard of 450 N/mm^2. The differences were statistically insignificant at the 95% level of confidence.

Table 6.1 VHP Steel Coupon Test Results

Maximum Load	Control Samples (0 ppm) Tension Test Results, N				Half-Target Concentration (125–150 ppm) Results, N			Target Concentration (250–300 ppm) Results, N		
	Test 1	Test 2	Test 3	Test 4	Test 1	Test 2	Test 3	Test 1	Test 2	Test 3
Coupon set	SN50310	SSN50622	SN50228	SSN50623	SV50420	SV50603	SV50606	SV50405	SV50517	SV50518
Coupon 1	60975	65766	61284	60627	61175	62453	60493	60393	60430	61121
Coupon 2	60402	61079	60997	62074	61559	59570	62283	60655	61194	61034
Coupon 3	60577	62921	60848	64483	60806	61380	62932	61793	61180	61321
Coupon 4	59711	64075	61109	61238	60731	64594	62046	60245	60959	61202
Coupon 5	60725	61732	60600	63661	60900	63982	62257	61148	61401	61524
Test Average	60478	63115	60968	62417	61034	62396	62002	60847	61033	61240
Standard Deviation	477	1874	260	1622	338	2023	907	631	371	191
Test Set Average ± Standard Deviation	61744 ± 1597				61811 ± 1337			61040 ± 437		
Tensile Strength	**Control Samples (0 ppm) Tensile Strength, N/mm²**				**Half-Target Concentration (125–150 ppm) Results, N/mm²**			**Target Concentration (250–300 ppm) Results, N/mm²**		
	Test 1	**Test 2**	**Test 3**	**Test 4**	**Test 1**	**Test 2**	**Test 3**	**Test 1**	**Test 2**	**Test 3**
Coupon set	SN50310	SSN50622	SN50228	SSN50623	SV50420	SV50603	SV50606	SV50405	SV50517	SV50518
Coupon 1	565	577	538	532	537	548	531	559	530	566
Coupon 2	559	509	565	545	570	523	577	562	537	565
Coupon 3	561	552	563	566	563	511	552	572	537	538
Coupon 4	524	562	566	567	562	567	544	558	535	537
Coupon 5	562	542	561	589	534	561	494	566	539	540
Test Average	554	548	559	560	553	542	540	563	535	549
Standard Deviation	17	26	12	22	17	24	30	6	3	15
Test Set Average ± Standard Deviation	555 ± 19				545 ± 23			549 ± 15		
Number of Days in Storage	**Control Samples (0 ppm) Days**				**Half-Target Concentration Days**			**Target Concentration Days**		
	Test 1	**Test 2**	**Test 3**	**Test 4**	**Test 1**	**Test 2**	**Test 3**	**Test 1**	**Test 2**	**Test 3**
Coupon set	SN50310	SSN50622	SN50228	SSN50623	SV50420	SV50603	SV50606	SV50405	SV50517	SV50518
Coupon 1	95	98	98	97	107	96	93	92	104	103
Coupon 2	95	98	98	97	107	96	93	92	104	103
Coupon 3	95	98	98	97	107	96	93	92	104	103
Coupon 4	95	98	98	97	107	96	93	92	104	103
Coupon 5	95	98	98	97	107	96	93	92	104	103
Test Set Average ± Standard Deviation	97 ± 1				99 ± 6			100 ± 6		

7.0
Evaluation of Gypsum Wallboard

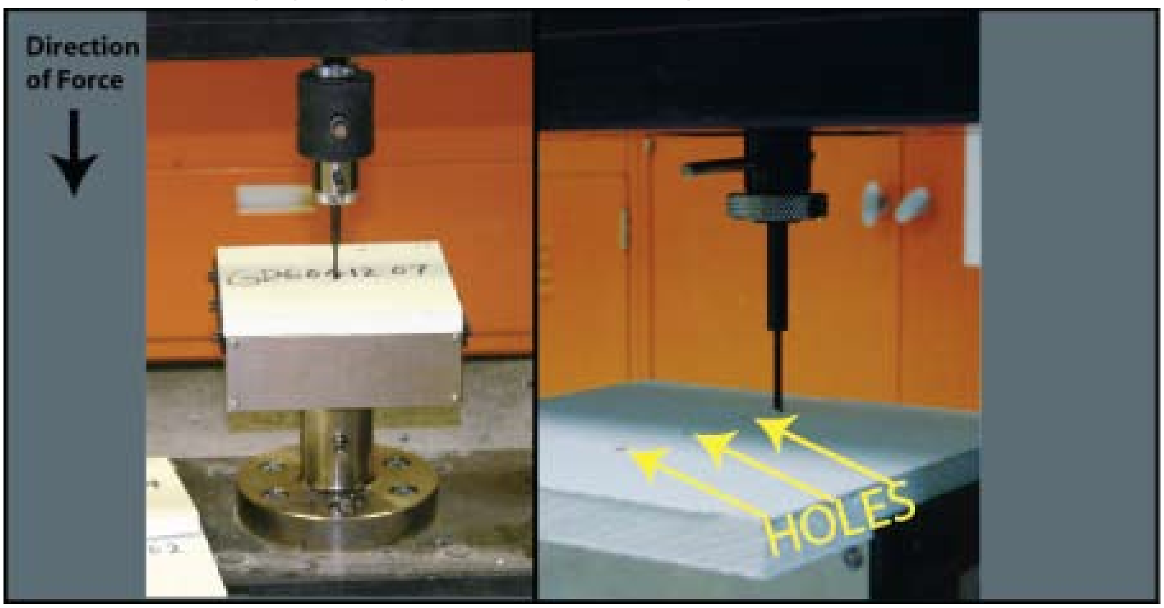
7.1 Introduction

The effects of VHP on the physical integrity of gypsum wallboard were investigated using the nail pull-through resistance test method B as described in ASTM Test Method C473-03 “Standard Test Methods for Physical Testing of Gypsum Panel Products” Section 13. The test measures the ability of the wallboard to resist nail pull-through by determining the load required to push a standard nail through the wallboard. The ASTM test was used to determine the integrity of gypsum wallboard coupons exposed to vaporous decontaminant compared to unexposed (control) gypsum wallboard coupons.

7.2 Sample Preparation and Testing

The gypsum wallboard samples were removed from storage, visually inspected, and measured. The coupons from chamber positions 1, 2, 4, 5, and 7 were selected for testing in order to obtain representation throughout the test chamber. The samples were brought to moisture equilibrium such that the weight of the sample did not change by more than 0.2% on successive weighings at a minimum interval of two hours. The sample preparation was conducted within a range of 15–25°C and 48–75% RH. The testing was conducted in accordance with ASTM Test Method C473-03. The Instron fixture for the gypsum wallboard test was installed prior to testing. The Instron universal testing machine operation was verified by suspending a certified weight from the fixture and recording the weight. Three coupons were tested for each concentration (full-target and half-target), and four sets were tested for the controls (0 ppm). The force required to drive a nail shank through the wallboard coupons was measured in N, with five replicate measurements made for each coupon (i.e., each coupon was punctured five times). The ASTM method indicates that any coupon measurement in the series that varies 15% more than the average needs to be discarded. If 15% of the coupons deviate from the average, the method states that the test will be repeated. No additional precision or bias requirements have been determined for this test by ASTM. The results for the control coupons are compared against the results for the decontaminant-exposed coupons. A statistical analysis of the data was conducted to determine whether the decontaminant-exposed coupon results were statistically different from the control coupon results. A photograph of a representative gypsum wallboard sample before and after testing (i.e., with holes) is provided in Figure 7.1.

Figure 7.1 Photograph – Gypsum Wallboard Coupon Test



7.3 Results

The coupons were stored for at least 90 days after fumigation. The actual number of storage days was based on the arrival of the Instron fixture for testing. The coupons for a particular fumigation were studied at the same number of days. Values for the load required to push the nail through the wallboard coupons and number of days in storage before testing are provided in Table 7.1.

7.4 Discussion

A statistical analysis of the test group results was conducted to detect potential statistical outliers (Q-test) and determine whether there were any differences between the control and exposed samples (Welch's T-test). Although there was a great deal of scatter in the data (the standard deviations of the results were between 14 and 22% of the mean value within the various test groups), none of the individual coupons was determined to be outliers at the Q=0.99 confidence level.

The average tension test results were 48.6 ± 7.0 N for the control group, 56.6 ± 12.8 N for the half-target group, and 63.3 ± 9.5 N for the full-target group. The Welch's T-test was used to determine whether there were statistically significant differences among the test groups (control, half-, and full-target). The control test group was statistically significantly different from the full-target and the half-target test groups at the 95% confidence level. However, the half-target and full-target test groups were not significantly different at the 95% level of confidence.

These test methods show that exposure to VHP has statistically significant effects on the maximum load of wallboard coupons as determined by the ATSM test method. Exposure to either VHP fumigation resulted in an increase in the ability of the wallboard to resist nail pull-through. However, this test does not indicated whether this decrease in maximum load would result in failure of installed wallboard after fumigation.

Table 7.1 Gypsum Wallboard Coupon Test Results for Maximum Load

VHP	Control Samples (0 ppm) Tension Test Results, N				Target Concentrations (250–300 ppm) Results, N			Half-Target Concentration (125–150 ppm) Results, N		
	Test 1	Test 2	Test 3	Test 4	Test 1	Test 2	Test 3	Test 1	Test 2	Test 3
Coupon set	GN50303	GN50401	GN50620	GN50621	GV50421	GV50526	GV50531	GV50407	GV50505	GV50506
Hole 1	47.2	40.2	59.1	48.1	71.8	70.2	56.3	60.7	65.6	46.5
Hole 2	53.8	42.5	45.3	47.5	72.7	62.4	51.0	61.6	64.4	37.1
Hole 3	64.1	41.3	55.3	46.0	67.5	72.8	53.5	75.3	54.5	43.5
Hole 4	56.6	36.5	47.2	52.7	60.2	83.2	54.0	78.7	65.9	48.8
Hole 5		45.6	45.0	54.4	58.8	70.7	53.3	71.4	52.3	40.9
Test Average	55.4	41.2	50.4	49.7	66.2	71.8	53.6	69.5	60.5	43.3
Standard Deviation	7.0	3.3	6.4	3.6	6.4	7.5	1.9	8.1	6.6	4.6
Test Set Average ± Standard Deviation	48.6 ± 7.0				63.3 ± 9.5			56.6 ± 12.8		

8.0 Evaluation of Acoustical Ceiling Tile

8.1 Introduction

The effects of VHP on the physical integrity of ceiling tile were investigated using the transverse strength test as described in ASTM Test Method C367-99 “Standard Test Methods for Strength Properties of Prefabricated Architectural Acoustical Tile or Lay-In Ceiling Panels” Sections 1, 3–5, and 21–29. The test measures the force required to cause the tile to break. The ASTM test was used to determine the integrity of ceiling tile coupons exposed to vaporous decontaminant compared to unexposed (control) ceiling tile coupons.

8.2 Sample Preparation and Testing

The acoustical ceiling tile samples were removed from storage, visually inspected, and measured. The samples were brought to moisture equilibrium such that the weight of the sample did not change by more than 1% on successive weighings at a minimum interval of two hours. The sample preparation was conducted within a range of 18–24 °C and 48–75% RH. The testing was conducted in accordance with ASTM Test Method C367-99. The Instron fixture for the ceiling tile test was installed prior to testing. The Instron universal testing machine operation was verified by suspending a certified weight from the fixture and recording the weight. For each test the coupons from chamber positions 1 through 8 were selected for testing; this selection resulted in placing all coupons in the chamber during a single fumigation trial. Ceiling tile coupons were tested in two directions — with the mandrel parallel to the axis of the test machine (hereafter referred to as “machine direction”) and with the mandrel perpendicular to the axis (“cross-machine direction”). Three sets of four machine-direction coupons and four cross-machine direction coupons were tested for each concentration (0 ppm, target, and half-target). The load required to break the ceiling tile coupons was measured in N. Figure 8.1 shows a photograph of a coupon loaded into the Instron for the machine direction and cross-machine direction tests. No precision or bias requirements have been established for this test method. The results for the control coupons have been compared to the results for the decontaminant-exposed coupons. A statistical analysis of the data was conducted to determine whether the decontaminant exposed coupon results were statistically different from the control coupon results.

The Modulus of Rupture (MOR) was calculated according to the test method, using the following equation:

$$\text{MOR units N/mm}^2\ (\text{lb/in}^2) = \frac{3 \times P \times L}{2 \times b \times d^2}$$

where P is the maximum load, N (lbf)

L is the length of span, mm (in.)

b is the specimen width, mm (in.)

d is the specimen thickness, mm (in.)

Figure 8.1 Photograph – Acoustical Ceiling Tile Coupon Test

8.3 Results

The coupons were stored for at least 90 days after fumigation. The actual number of storage days was based on the arrival of the Instron fixture for testing. The coupons for a particular fumigation were studied at the same number of days. A photograph of a representative ceiling tile sample before and after testing is provided in Figure 8.2. Values for the load required to rupture the ceiling tile coupons, the ceiling tile coupon MOR results, and number of days in storage are provided Table 8.1.

8.4 Discussion

A statistical analysis of the individual test results was conducted to detect potential statistical outliers (Q-test) and determine whether there were any differences between the control and exposed samples (Welch's T-test). None of the coupons could be eliminated as statistical outliers from within their individual test sets or test groups (control, half-target concentration, or full-target concentration samples) at the Q=0.99 level of confidence.

For the machine-direction tests, the maximum load values were as follows: 35.23 ± 4.92 N for the controls, 40.76 ± 5.20 N for the half-target coupons, and 36.63 ± 4.07 N for the full-target coupons. The moduli of rupture were: 0.82 ± 0.11 N/mm² for the controls, 0.97 ± 0.15 N/mm² for the half-target, and 0.82 ± 0.11 N/mm² for the full-target coupons.

For the cross-machine tests, the maximum load values were as follows: 28.83 ± 5.02 N for the controls, 32.18 ± 3.22 N for the half-target coupons, and 27.23 ± 3.69 N for the full-target coupons. The moduli of rupture were: 0.67 ± 0.12 N/mm² for the controls, 0.76 ± 0.07 N/mm² for the half-target, and 0.62 ± 0.08 N/mm² for the full-target coupons.

In all cases, the cross-machine test results were lower than those in the machine direction orientation.

With regard to the individual coupon sets tested, there were obvious variations among the test groups (control, half-target exposure, or full-target exposure). In both the machine direction and cross-machine tests, the half-concentration coupons had higher maximum loads and moduli of rupture. For the machine direction tests, the half-target results were significantly different from the results for both the control test coupons and the full-target coupons at a 95% confidence level. The control coupons and full-target coupons were not, however, significantly different at the 95% confidence level.

For the cross-machine tests, the control coupons were not significantly different from either the half- or full-target coupons at the 95% level of confidence.

From these test methods, it is not clear that the VHP fumigation process has, overall, a statistically significant effect on the maximum load and the modulus of rupture of acoustic ceiling tile. The maximum load and modulus of rupture did increase due to long exposure (8 hours) at the lower concentration (150 ppm); however, the effect was only significant in the machine-direction tests.

Figure 8.2 Representative Break – Acoustical Ceiling Tile Coupons

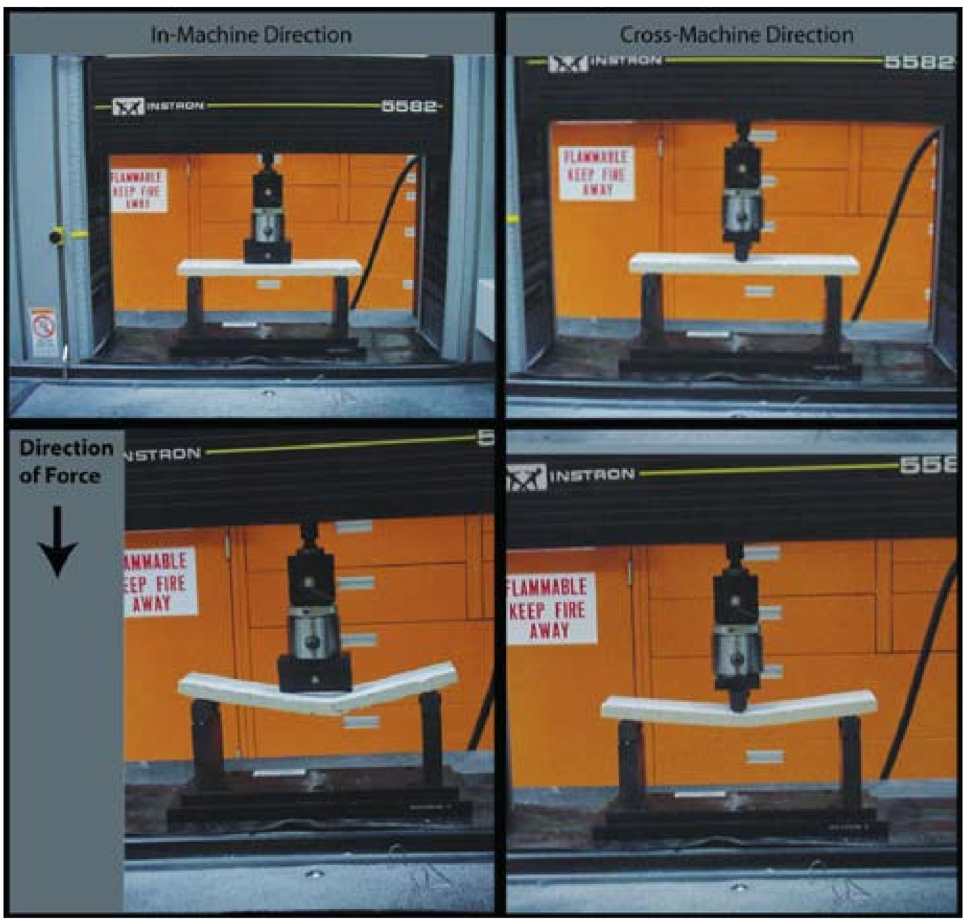


Table 8.1 VHP Coupon Test Results for Tile

Maximum Load Machine Direction	Control Samples (0 ppm) Tension Test Results, N			Half-Target Concentration (125–150 ppm) Results, N			Target Concentration (250–300 ppm) Results, N		
	Test 1	Test 2	Test 3	Test 1	Test 2	Test 3	Test 1	Test 2	Test 3
Coupon set	TN50307	TN50610	TN50613	TV50418	TV50511	TV50601	TV50316	TV50427	TV50428
Coupon 1	36.00	37.11	28.74	45.12	48.61	45.00	33.27	39.54	41.34
Coupon 2	30.28	41.46	40.05	44.01	37.78	43.26	30.40	33.40	40.98
Coupon 3	32.16	41.72	35.61	39.09	36.73	31.50	40.17	35.46	33.96
Coupon 4	33.62	27.11	38.88	45.36	34.38	38.22	33.52	42.76	34.73
Test Average	33.02	36.85	35.82	43.40	39.38	39.50	34.34	37.79	37.75
Standard Deviation	2.41	6.83	5.08	2.93	6.32	6.06	4.14	4.18	3.95
Test Set Average ± Standard Deviation	35.23 ± 4.92			40.76 ± 5.20			36.63 ± 4.07		
Modulus of Rupture Machine Direction	**Control Samples (0 ppm) Tensile Strength, N/mm²**			**Half-Target Concentration (125–150 ppm) Results, N/mm²**			**Target Concentration (250–300 ppm) Results, N/mm²**		
	Test 1	Test 2	Test 3	Test 1	Test 2	Test 3	Test 1	Test 2	Test 3
Coupon set	TN50307	TN50610	TN50613	TV50418	TV50511	TV50601	TV50316	TV50427	TV50428
Coupon 1	0.83	0.86	0.67	1.05	1.31	1.04	0.77	0.92	0.96
Coupon 2	0.69	0.96	0.93	1.02	0.88	1.00	0.70	0.77	0.83
Coupon 3	0.74	0.97	0.82	0.89	1.00	0.73	0.93	0.82	0.69
Coupon 4	0.78	0.63	0.90	1.05	0.80	0.89	0.78	0.99	0.69
Test Average	0.76	0.85	0.83	1.00	0.99	0.91	0.80	0.88	0.79
Standard Deviation	0.06	0.16	0.12	0.07	0.22	0.14	0.10	0.10	0.13
Test Set Average ± Standard Deviation	0.82 ± 0.11			0.97 ± 0.15			0.82 ± 0.11		
Maximum Load Cross-Machine	**Control Samples (0 ppm) Tension Test Results, N**			**Half-Target Concentration (125–150 ppm) Results, N**			**Target Concentration (250–300 ppm) Results, N**		
	Test 1	Test 2	Test 3	Test 1	Test 2	Test 3	Test 1	Test 2	Test 3
Coupon set	TN50307	TN50610	TN50613	TV50418	TV50511	TV50601	TV50316	TV50427	TV50428
Coupon 1	20.08	29.97	30.85	40.17	34.79	31.47	25.19	23.80	24.86
Coupon 2	25.63	30.15	34.15	30.74	28.86	31.06	23.17	22.55	26.93
Coupon 3	23.33	26.17	30.07	30.98	33.82	33.10	27.38	34.69	26.67
Coupon 4	24.38	37.15	34.00	28.69	33.40	29.08	31.54	30.17	29.84
Test Average	23.36	30.86	32.27	32.65	32.72	31.18	26.82	27.80	27.08
Standard Deviation	2.38	4.58	2.11	5.12	2.64	1.65	3.59	5.68	2.06
Test Set Average ± Standard Deviation	28.83 ± 5.02			32.18 ± 3.22			27.23 ± 3.69		
Modulus of Rupture Cross-Machine	**Control Samples (0 ppm) Tensile Strength, N/mm²**			**Half-Target Concentration (125–150 ppm) Results, N/mm²**			**Target Concentration (250–300 ppm) Results, N/mm²**		
	Test 1	Test 2	Test 3	Test 1	Test 2	Test 3	Test 1	Test 2	Test 3
Coupon set	TN50307	TN50610	TN50613	TV50418	TV50511	TV50601	TV50316	TV50427	TV50428
Coupon 1	0.47	0.69	0.71	0.93	0.81	0.73	0.58	0.55	0.58
Coupon 2	0.59	0.70	0.79	0.71	0.78	0.72	0.54	0.52	0.62
Coupon 3	0.54	0.61	0.70	0.72	0.78	0.77	0.63	0.80	0.62
Coupon 4	0.56	0.86	0.79	0.66	0.78	0.67	0.73	0.70	0.60
Test Average	0.54	0.71	0.75	0.76	0.79	0.72	0.62	0.64	0.60
Standard Deviation	0.05	0.11	0.05	0.12	0.01	0.04	0.08	0.13	0.02
Test Set Average ± Standard Deviation	0.67 ± 0.12			0.76 ± 0.07			0.62 ± 0.08		
Number of Days in Storage	**Control Samples (0 ppm) Days**			**Half-Target Concentration Days**			**Target Concentration Days**		
	Test 1	Test 2	Test 3	Test 1	Test 2	Test 3	Test 1	Test 2	Test 3
Coupon set	TN50307	TN50610	TN50613	TV50418	TV50511	TV50601	TV50316	TV50427	TV50428
	191	284	281	184	183	299	189	189	188
Test Set Average ± Standard Deviation	252 ± 53			222 ± 67			189 ± 1		

9.0 Evaluation of Carpet

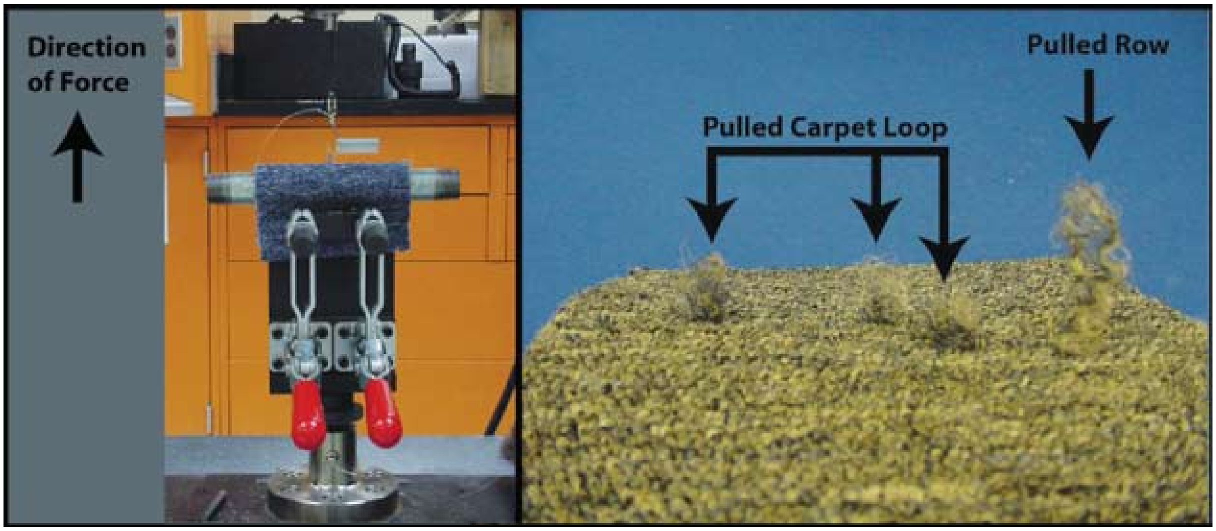
9.1 Introduction

The effects of VHP on the physical integrity of loop pile carpet fibers were investigated using ASTM Test Method C1335-03 “Standard Test Method for Tuft Bind of Pile Yarn Floor Coverings.” The method determines the force required to pull out a tuft of a pile yarn from a floor-covering sample. The ASTM test was used to determine the integrity of loop pile carpet fibers exposed to vaporous decontaminant compared to unexposed (control) loop pile carpet fibers.

9.2 Sample Preparation

The carpet samples were removed from storage, visually inspected, and measured. The coupons from chamber positions 1, 3, 4, 5, and 7 were selected for testing in order to obtain representation throughout the test chamber. The samples were brought to moisture equilibrium such that the weight of the sample did not change by more than 0.2% on successive weighings at a minimum interval of two hours. The sample preparation was conducted within a range of 15–24 °C and 48–75% RH. The testing was conducted in accordance with ASTM Test Method D1335-03. The Instron fixture for the carpet test was installed prior to testing. The Instron universal testing machine operation and calibration verification was conducted by suspending a certified weight from the fixture and recording the weight. Three sets of five coupons were tested for each concentration (full-target and half-target) and four sets were tested for the controls (0 ppm). The load required to pull a carpet loop from the binding was measured in N, and five replicate measurements were made for each coupon. No bias requirements have been established for this test method. The results for control coupons were compared to the results for decontaminant-exposed coupons. A statistical analysis of the data was conducted to determine whether the decontaminant-exposed coupon results were statistically different from the control coupon results. A photograph of a representative carpet sample before and after testing is provided in Figure 9.1

Figure 9.1 Photograph – Carpet Coupon Test



9.3 Results

The coupons were stored for at least 90 days after fumigation. The actual number of storage days was based on the arrival of the Instron fixture for testing. The coupons for a particular fumigation were studied at the same number of days. Values from the carpet tuft bind results and number of days in storage are provided in Table 9.1.

9.4 Discussion

A statistical analysis of the individual test results was conducted to detect potential statistical outliers (Q-test) and determine whether there were any differences between the control and exposed samples (Welch's T-test). Although there was a great deal of scatter in the data (the standard deviations of the results were 25% of the mean value within the various test groups), none of the coupons was determined to be outliers at the Q=0.99 confidence level.

The values for the average tuft bind for the groups of coupons were as follows: 14.8 ± 3.7 N for the control coupons, 16.8 ± 4.0 N for the half-target coupons, and 15.3 ± 3.7 N for the full-target coupons.

There are variations among the test groups (control, half-target exposure, or full-target exposure) at the 95% confidence level. While the difference between the control group and the full-target group are statistically insignificant, the half-target values are statistically different from the controls and full-target groups. The results suggest that VHP fumigation at the half-target concentration for long exposure times (8 hours) may have an effect on the tuft bind tests of carpet coupons as determined by our test methods. The fumigation made it more difficult, i.e., greater bind force was necessary, to pull a tuft out of the test carpet used in this study.

Table 9.1 Carpet Coupon Test Results for Average Tuft Bind - VHP Control Samples

Turf Bind Force	Control Sample (0 ppm) Results, N														
	RN50309					RN50309					RN50614				
Coupon	#1	#2	#3	#4	#5	#1	#2	#3	#4	#5	#1	#2	#3	#4	#5
Loop 1	12.5	15.9	14.7	11.0	9.5	12.5	15.9	14.7	11.0	9.5	21.9	23.1	24.4	12.2	9.6
Loop 2	14.9	13.1	8.0	15.9	16.2	14.9	13.1	8.0	15.9	16.2	13.7	21.6	18.9	8.4	18.0
Loop 3	10.8	13.7	14.1	9.2	12.5	10.8	13.7	14.1	9.2	12.5	19.0	20.2	16.5	14.3	13.8
Loop 4			8.9	14.3	14.1			8.9	14.3	14.1	15.3	18.3	14.1		13.1
Loop 5			19.2					19.2			16.9		15.0		18.6
Test Average	12.7	14.3	13.0	12.6	13.1	12.7	14.3	13.0	12.6	13.1	17.3	20.8	17.8	11.6	14.6
Standard Deviation	2.0	1.5	4.6	3.0	2.9	2.0	1.5	4.6	3.0	2.9	3.2	2.0	4.1	3.0	3.7
Days in Storage	147					147					148				
	RN50615														
Coupon	#1	#2	#3	#4	#5										
Loop 1	11.9	17.1	13.4	19.0	18.2										
Loop 2	18.7	10.9	15.4	13.6	14.1										
Loop 3	10.0	10.6	16.6	13.0	10.5										
Loop 4	19.2	17.6		16.2	11.9										
Loop 5	14.9	10.7		15.5	16.1										
Test Average	14.9	13.4	15.2	15.5	14.1										
Standard Deviation	4.1	3.6	1.6	2.4	3.1										
Days in Storage	147														
Test Set Average ± Standard Deviation	14.8 ± 3.7														
Turf Bind Force	Target Concentration (250–300 ppm) Results, N														
	RV50419					RV50519					RV50520				
Coupon	#1	#2	#3	#4	#5	#1	#2	#3	#4	#5	#1	#2	#3	#4	#5
Loop 1	11.2	12.5	15.3	19.8	10.4	10.5	15.1	11.5	18.0	21.3	16.8	16.5	16.6	10.0	13.1
Loop 2	18.0	12.9	10.0	13.0	14.2	19.1	21.8	8.3	12.2	15.8	12.5	17.3	11.9	21.7	11.2
Loop 3	16.0	11.0	15.6	19.8	16.5	20.7	15.5	11.6	14.0	14.1	18.0	14.1	10.3	17.6	14.6
Loop 4	19.2		11.6	20.7	18.4	23.5	12.8			16.8			10.2	11.3	
Loop 5	16.2			17.7	16.6	12.5	21.3			16.2				18.4	
Test Average	16.1	12.1	13.1	18.2	15.2	17.2	17.3	10.5	14.7	16.8	15.7	16.0	12.2	15.8	13.0
Standard Deviation	3.0	1.0	2.8	3.1	3.1	5.6	4.0	1.8	2.9	2.7	2.8	1.6	3.0	5.0	1.7
Days in Storage	147					148					147				
Test Set Average ± Standard Deviation	15.3 ± 3.7														
Turf Bind Force	Half-Target Concentration (125–150 ppm) Results, N														
	RV50321					RV50429					RV50502				
Coupon	#1	#2	#3	#4	#5	#1	#2	#3	#4	#5	#1	#2	#3	#4	#5
Loop 1		12.0	14.7	16.5	12.2	15.3	16.8	12.7	25.6	15.1	17.7	11.0	13.0	13.2	15.9
Loop 2		20.7	20.7	16.2	19.1	18.8	23.7	13.0	16.3	21.2	19.4	18.2	10.6	13.5	14.8
Loop 3		12.2	10.9	19.4	14.5	12.3	15.8	19.0	18.3	19.2	13.1	7.7	19.0	15.9	13.8
Loop 4		15.1	16.0		18.2	22.4	26.2	20.7	14.6	15.7	14.0	18.5	15.7		
Loop 5		19.9	23.6		15.0	16.9	25.5	20.3	21.7			18.5	11.7		
Test Average		16.0	17.2	17.4	15.8	17.1	21.6	17.1	19.3	17.8	16.0	14.8	14.0	14.2	14.8
Standard Deviation		4.2	5.0	1.8	2.8	3.8	4.9	4.0	4.4	2.9	3.0	5.1	3.4	1.5	1.1
Days in Storage	161					152					149				
Test Set Average ± Standard Deviation	16.8 ± 4.0														

Note: The cells highlighted in gray are samples that were not required to be analyzed, due to meeting the test method sampling criteria of ±15%.

10.0
Evaluation of Concrete Cinder Block

10.1 Introduction

The effects of VHP on the physical integrity of concrete cinder block coupons were investigated using the compression test as described in ASTM Test Method C140-03 "Standard Test Methods for Sampling and Testing Concrete Masonry Units and Related Units." The ASTM test was used to determine the integrity of the concrete cinder block coupons exposed to vaporous decontaminant compared to unexposed (control) concrete cinder block coupons.

10.2 Sample Preparation and Testing

The concrete cinder block samples were removed from storage, visually inspected, and measured. The coupons from chamber positions 1, 4, and 7 were selected for testing in order to obtain representation throughout the test chamber. The samples were placed in an environmental range of 16–32 °C and less than 80% RH for 48 hours prior to testing. The testing was conducted in accordance with ASTM Test Method C140-03. The Instron fixture for the concrete cinder block test was installed prior to testing. A photograph of a concrete cinder block coupon loaded into the Instron test apparatus is shown in Figure 10.1. The Instron universal testing machine operation and calibration verification was conducted by suspending a certified weight from the fixture and recording the weight. Three sets of three coupons were tested for each concentration (0 ppm, full-target, and half-target). The load required to rupture the coupons was measured in kgf/mm^2 and can be found in Table 10.1. No precision or bias requirements have been established for this test method. The results for control coupons were compared to the results for decontaminant-exposed coupons. A statistical analysis of the data was conducted to determine whether the decontaminant-exposed coupon results were statistically different from the control coupon results.

Figure 10.1 Photograph – Concrete "Cinder Block" Coupon Test

10.3 Results

The coupons were stored for at least 90 days after fumigation. The actual number of storage days was based on the arrival of the Instron fixture for testing. The coupons for a particular fumigation were studied at the same number of days. A photograph of a representative concrete cinder block sample before and after testing is provided in Figure 10.2. The coloring difference between the samples in the picture is a result of room lighting and is not real. Both samples were taken on the same blue color mat. Values for the load required to crush the concrete cinder block coupons, the coupon gross area compressive strength results, and number of days in storage are provided in Table 10.1. The concrete cinder block is a heterogeneous material sample to sample. The break patterns varied from sample to sample; a photograph of each sample is provided in Appendix D.

10.4 Discussion

A statistical analysis of the individual test results was conducted to detect potential statistical outliers (Q-test) and determine whether there were any differences between the control and exposed samples (Welch's T-test). None of the coupons could be eliminated as statistical outliers from within their individual test sets or test groups (control, half-target concentration, or full-target concentration samples) at the Q=0.99 level of confidence.

A Welch's T-test evaluation of the data for both maximum load and gross area compressive strength indicated that there were no statistically significant differences among the means of the exposed and control samples at the 95% confidence level. These test methods indicated that exposure to VHP had no significant effect on the maximum load or the gross area compressive strength of cinder blocks.

Figure 10.2 Representative Concrete Coupons Before and After Testing

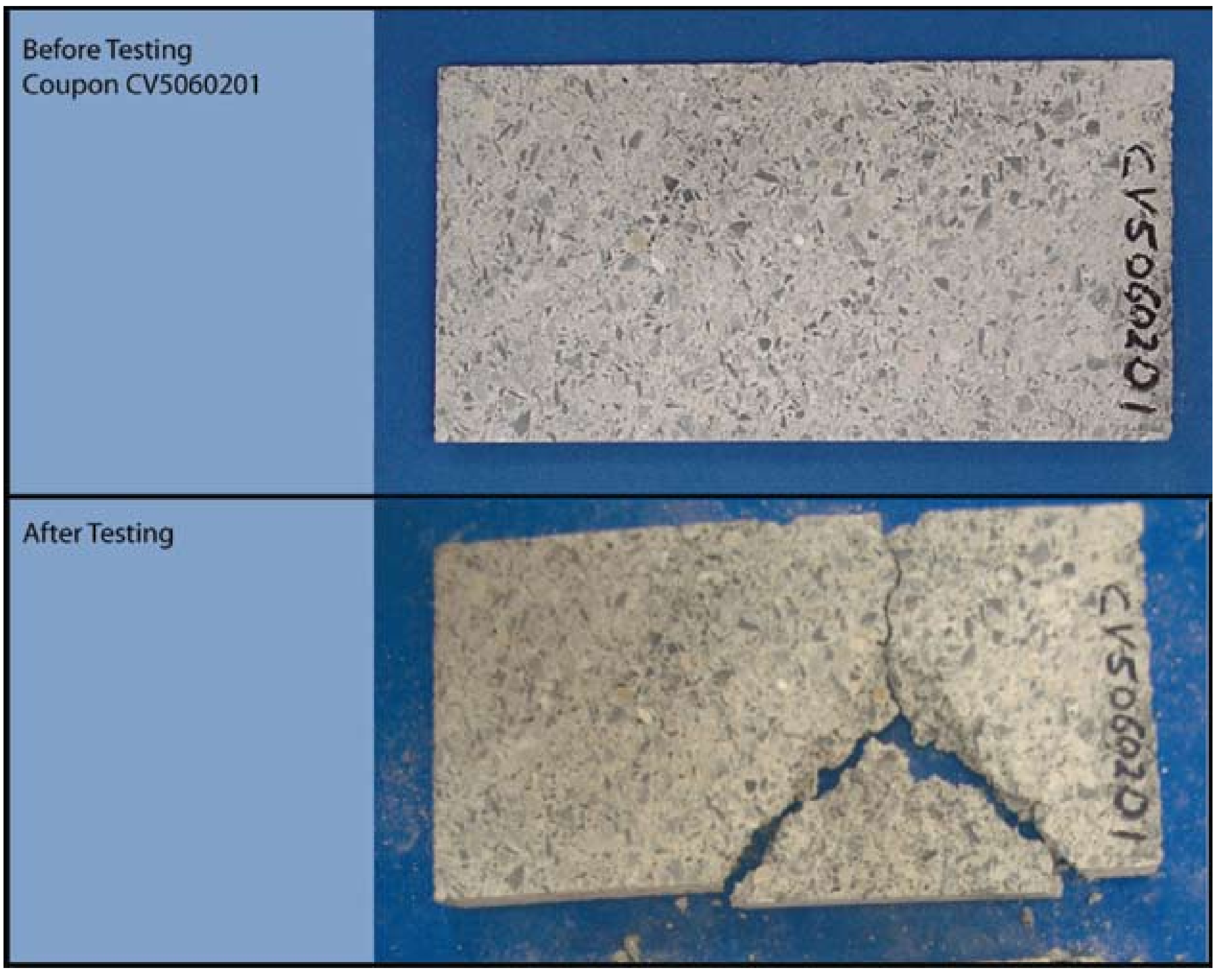


Table 10.1 VHP Coupon Test Results for Concrete Cinder Block

Maximum Load	**Control Samples (0 ppm) kgf**			**Half-Target Concentration (125–150 ppm) Results, kgf**			**Target Concentration (250–300 ppm) Results, kgf**		
	Test 1	**Test 2**	**Test 3**	**Test 1**	**Test 2**	**Test 3**	**Test 1**	**Test 2**	**Test 3**
Coupon set	CN50331	CN50617	CN50616	CV50524	CV50525	CV50602	CV50404	CV50503	CV50504
Coupon 1	4084	3869	2905	5094	5902	4583	2800	4378	3286
Coupon 2	4686	4491	1932	2634	4317	5026	3598	4165	2935
Coupon 3	4512	4731	3432	2993	4330	3988	2614	4050	3670
Test Average	4427	4364	2757	3574	4850	4532	3004	4197	3297
Standard Deviation	310	445	761	1329	911	521	523	167	367
Test Set Average ± Standard Deviation	3849 ± 944			4319 ± 1024			3500 ± 632		
Gross Area Compressive Strength	**Control Samples (0 ppm) kgf/mm²**			**Half-Target Concentration (125–150 ppm) Results, kgf/mm²**			**Target Concentration (250–300 ppm) Results, kgf/mm²**		
	Test 1	**Test 2**	**Test 3**	**Test 1**	**Test 2**	**Test 3**	**Test 1**	**Test 2**	**Test 3**
Coupon set	CN50331	CN50617	CN50616	CV50524	CV50525	CV50602	CV50404	CV50503	CV50504
Coupon 1	3.2	1.8	1.5	2.6	2.8	2.3	2.5	2.3	2.0
Coupon 2	3.6	2.1	0.9	1.3	2.2	2.4	3.7	2.1	2.0
Coupon 3	4.0	2.2	1.8	1.4	2.3	2.1	2.3	2.3	1.9
Test Average	3.6	2.0	1.4	1.8	2.4	2.3	2.8	2.2	2.0
Standard Deviation	0.4	0.2	0.4	0.7	0.3	0.1	0.8	0.1	0.1
Test Set Average ± Standard Deviation	2.3 ± 1.0			2.2 ± 0.5			2.3 ± 0.5		
Number of Days in Storage	**Control Sample (0 ppm) Days**			**Half-Target Concentration Days**			**Target Concentration Days**		
	Test 1	**Test 2**	**Test 3**	**Test 1**	**Test 2**	**Test 3**	**Test 1**	**Test 2**	**Test 3**
Coupon set	CN50331	CN50617	CN50616	CV50524	CV50525	CV50602	CV50404	CV50503	CV50504
Coupon 1	104	328	104	163	162	137	100	118	117
Coupon 2	104	328	104	163	162	137	100	118	117
Coupon 3	104	328	104	163	162	137	100	118	117
Test Set Average ± Standard Deviation	179 ± 112			154 ± 13			112 ± 9		

11.0 Evaluation of Wood

11.1 Introduction

The effects of VHP on the physical integrity of wood were investigated using the bending edge-wise test as described in ASTM Test Method D4761-02a "Standard Test Methods for Mechanical Properties of Lumber and Wood-Base Structural Material," Sections 6–11. The ASTM test was used to determine the integrity of wood coupons exposed to vaporous decontaminant compared to unexposed (control) wood coupons.

11.2 Sample Preparation

The wood samples were removed from storage, visually inspected, and measured. The coupons from chamber positions 1, 4, 7, 10, and 14 were selected for testing in order to obtain representation throughout the test chamber. The samples were brought to moisture equilibrium such that the weight of the sample did not change by more than 0.2% on successive weighings at a minimum interval of two hours. The sample preparation was conducted within a range of 15–25 °C and 48–75% RH. The testing was conducted in accordance with ASTM Test Method D4761-02a. The Instron fixture for the wood test was installed prior to testing. The Instron universal testing machine operation and calibration verification was conducted by suspending a certified weight from the fixture and recording the weight. Three sets of five coupons were tested for each concentration (0 ppm, full-target, and half-target). The load required to rupture the wood coupons was measured in N. The setup of the Instron for testing the wood furrings can be seen in Figure 11.1. No precision or bias requirements have been established for this test method. The results for control coupons were compared to the results for decontaminant-exposed coupons. A statistical analysis of the data was conducted to determine whether the decontaminant-exposed coupon results were statistically different from the control coupon results.

Figure 11.1 Photograph – Wood Coupon Test

11.3 Results

The coupons were stored for at least 90 days after fumigation. The actual number of storage days was based on the arrival of the Instron fixtures for testing. The coupons for a particular fumigation were studied at the same number of days. A photograph of a representative wood sample before and after testing is provided in Figure 11.2. The wood coupon results for the required load and time to break, moisture content, and number of days in storage are provided in Table 11.1. The wood samples vary slightly in knot and grain pattern from sample to sample. The break patterns varied from sample to sample; a photograph of each sample is provided in Appendix C.

11.4 Discussion

A statistical analysis of the individual test results was conducted to detect potential statistical outliers (Q-test) and determine whether there was a difference between the control and exposed samples (Welch's T-test). Within the target concentration test group, two coupons were outliers within their test sets with respect to both maximum force required to break and time-to-break values at the Q=0.99 confidence level. Of these two outliers, only Coupon 5 of Test 2 was an outlier within the entire test group of 15 coupons. This value was removed from the data sets before statistical analysis was performed. The moisture content of Coupon 4 of Test Set 2 for the half-target concentration test group was also noted as an outlier; however, it was not an outlier when considering the entire test group. Therefore, this value was retained.

With regard to the data from the test groups of coupons, the average maximum load values for the VHP-exposed coupons increased by 11–18% over the value for the control sets for both half-target concentration sets and full-target concentration sets. The time-to-break values for the exposed coupons were also higher (3–18%), but the moisture content values showed no trend.

The average maximum force value for the control samples was 4006 ± 861 N. The half-target concentration samples had an average maximum force value of 4431 ± 929 N (an increase of 10.6%), while the full-target concentration samples had an average maximum force value of 4725 ± 732 N (an increase of 17.9%).

The average time-to-break value for the control coupons was 3.9 ± 0.9 seconds. The half-target concentration coupons had an average time-to-break of 4.0 ± 0.9 seconds, and the full-target concentration coupons had an average time-to-break of 4.6 ± 0.7 seconds.

The average change in moisture content for the control samples after storage was –0.02 ± 0.13%. For the half-target concentration coupons, the average change in moisture content was +0.48 ± 0.52, and for the full-target concentration coupons the average change in moisture was –0.06 ± 0.13%.

The differences between the control samples and full-target concentration coupons with respect to the maximum force and time-to-break were statistically significant at the 95% confidence level. The half-target concentration samples were not statistically different from the controls.

The results suggest that VHP fumigation at the full-target conditions may have impacted the wood used for this study, according to the ASTM test method. The fumigation appeared to increase the force and time required to break the wood.

Figure 11.2 Representative Wood Coupon Before and After Testing

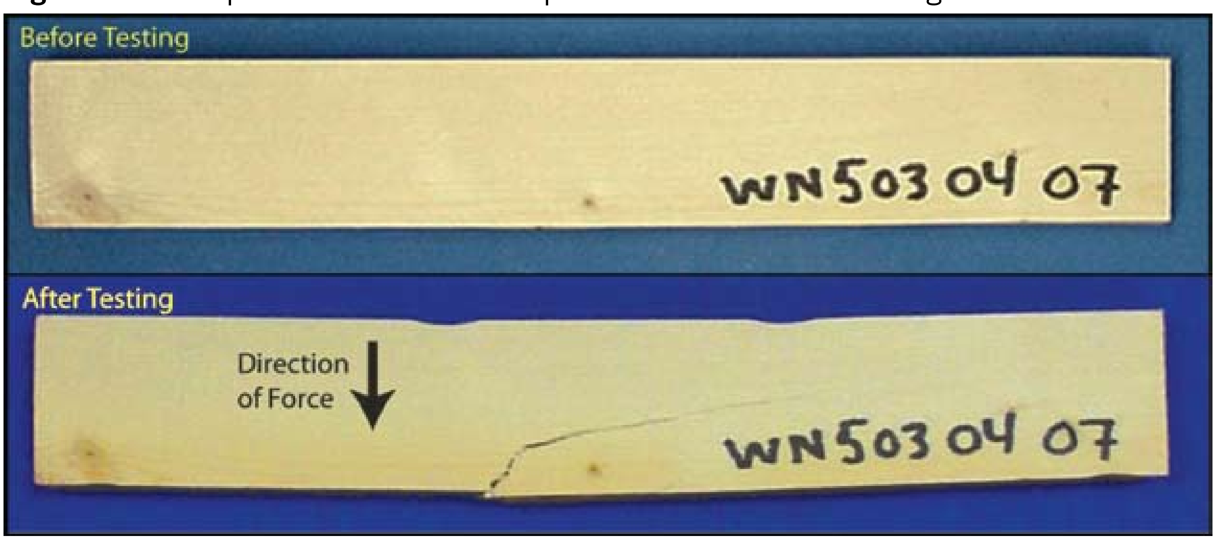


Table 11.1 VHP Coupon Test Results for Wood

Maximum Force	Control Sample (0 ppm) N			Half-Target Concentration (125–150 ppm) Results, N			Target Concentration (250–300 ppm) Results, N		
	Test 1	Test 2	Test 3	Test 1	Test 2	Test 3	Test 1	Test 2	Test 3
Coupon set	WN50304	WN50608	WN50609	WV50415	WV50509	WV50510	WV50406	WV50425	WV50426
Coupon 1	4562	4766	2475	3038	2873	6306	4730	4400	4202
Coupon 2	3782	4739	2888	4014	4389	4542	4951	5153	3023
Coupon 3	4539	3560	3038	3977	4877	4174	5045	4919	4715
Coupon 4	3858	4177	5312	5752	3717	3938	4862	4287	4394
Coupon 5	4076	3136	5175	4696	4842	5323	6428	1305	5040
Test Average	4163	4076	3777	4295	4140	4857	5203	4013	4275
Standard Deviation	369	721	1355	1006	849	965	695	1556	769
Test Set Average ± Standard Deviation	4006 ± 861			4431 ± 929			4725 ± 732		
Time to Break	**Control Sample (0 ppm) minutes**			**Half-Target Concentration (125–150 ppm) Results, minutes**			**Target Concentration (250–300 ppm) Results, minutes**		
	Test 1	Test 2	Test 3	Test 1	Test 2	Test 3	Test 1	Test 2	Test 3
Coupon set	WN50304	WN50608	WN50609	WV50415	WV50509	WV50510	WV50406	WV50425	WV50426
Coupon 1	4.6	4.6	2.4	3.0	2.9	5.5	4.7	4.1	4.1
Coupon 2	3.8	4.5	2.7	4.0	3.5	3.6	5.0	4.9	3.0
Coupon 3	4.5	3.3	2.9	4.0	3.8	3.4	5.0	4.6	4.7
Coupon 4	3.9	3.9	5.3	5.8	3.6	3.3	4.9	4.2	4.3
Coupon 5	4.1	2.7	5.2	4.7	4.5	4.9	6.4	1.3	4.8
Test Average	4.2	3.8	3.7	4.3	3.7	4.1	5.2	3.8	4.2
Standard Deviation	0.4	0.8	1.4	1.0	0.6	1.0	0.7	1.4	0.7
Test Set Average ± Standard Deviation	3.9 ± 0.9			4.0 ± 0.9			4.6 ± 0.7		
Moisture Content	**Control Sample (0 ppm) %**			**Half-Target Concentration (125–150 ppm) Results, %**			**Target Concentration (250–300 ppm) Results, %**		
	Test 1	Test 2	Test 3	Test 1	Test 2	Test 3	Test 1	Test 2	Test 3
Coupon set	WN50304	WN50608	WN50609	WV50415	WV50509	WV50510	WV50406	WV50425	WV50426
Coupon 1	0.15	-0.12	-0.12	-0.10	1.04	0.83	0.12	-0.05	-0.22
Coupon 2	0.09	-0.07	-0.10	-0.16	0.96	0.88	-0.02	-0.19	-0.15
Coupon 3	0.20	-0.18	-0.19	-0.17	0.91	0.83	0.14	-0.15	-0.13
Coupon 4	0.12	-0.12	-0.06	-0.05	-0.13	0.75	0.08	-0.15	-0.02
Coupon 5	0.18	-0.10	0.02	-0.15	0.93	0.84	0.16	-0.19	-0.11
Test Average	0.15	-0.12	-0.09	-0.13	0.74	0.83	0.10	-0.15	-0.12
Standard Deviation	0.04	0.04	0.08	0.05	0.49	0.05	0.07	0.06	0.07
Test Set Average ± Standard Deviation	-0.02 ± 0.13			0.48 ± 0.52			-0.06 ± 0.13		
Number of Days in Storage	**Control Sample (0 ppm) Days**			**Half-Target Concentration, Days**			**Target Concentration, Days**		
	Test 1	Test 2	Test 3	Test 1	Test 2	Test 3	Test 1	Test 2	Test 3
Coupon set	WN50304	WN50608	WN50609	WV50415	WV50509	WV50510	WV50406	WV50425	WV50426
Coupon 1	138	145	144	136	143	142	145	189	188
Coupon 2	138	145	144	136	143	142	145	189	188
Coupon 3	138	145	144	136	143	142	145	189	188
Coupon 4	138	145	144	136	143	142	145	189	188
Coupon 5	138	145	144	136	143	142	145	189	188
Test Set Average ± Standard Deviation	142 ± 3			142 ± 10			176 ± 21		

Note: The values highlighted in orange were determined to be outliers within their individual test sets but not within their individual test groups at the Q=0.99 confidence level. The values highlighted in red were determined to be outliers within the test set and test group and were, therefore, removed from the data set prior to statistical analysis.

12.0 Evaluation of Electrical Circuit Breakers

12.1 Introduction

The impact of fumigant and humidity on the performance of electrical circuit breakers was also investigated in this study. This investigation involved circuit breakers prepared as baseline, test, and control. Baseline circuit breakers are the "as-purchased" circuit breakers. The test circuit breakers were prepared in the exposure chambers using fumigant. The control circuit breakers were prepared in the exposure chambers using a temperature and relative humidity profile similar to that of the test breakers.

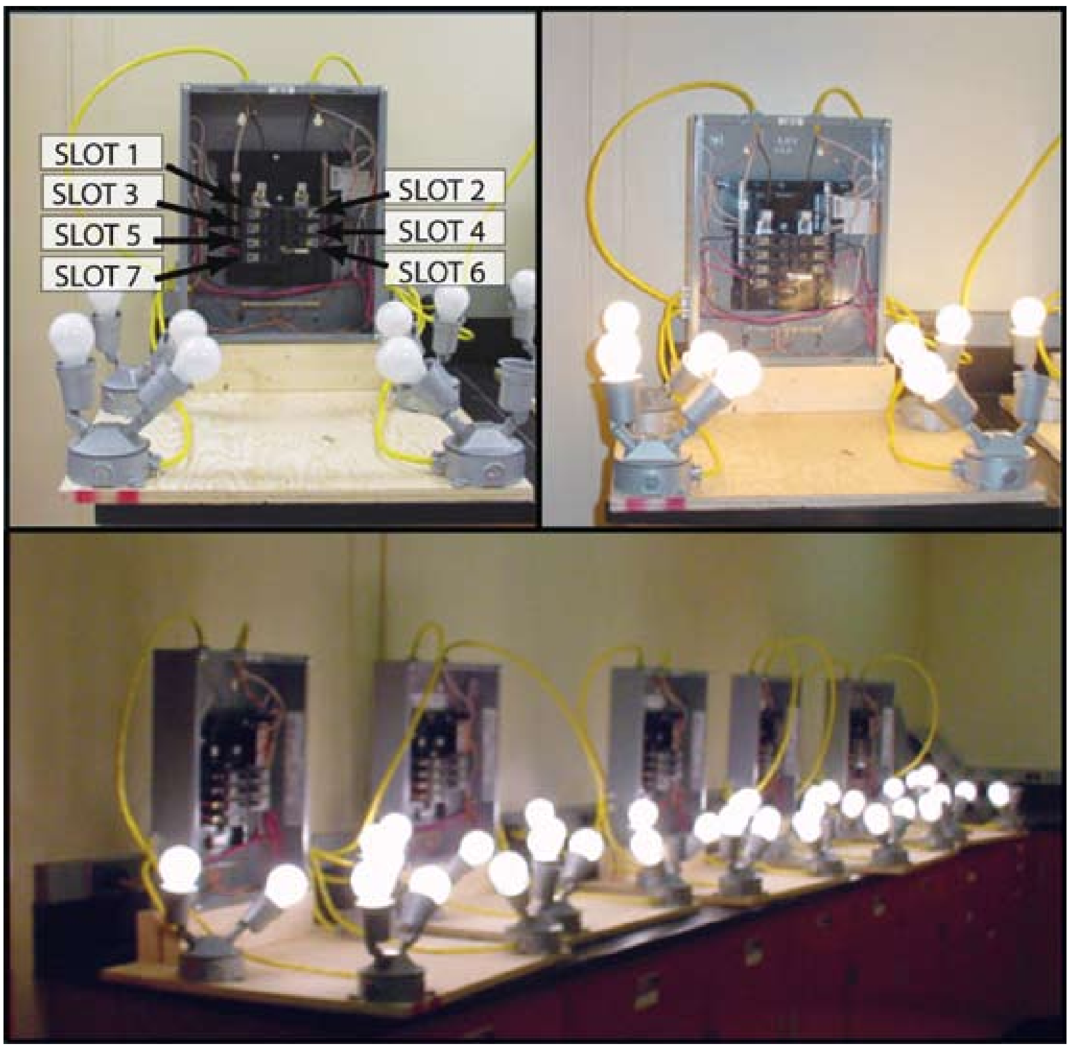
12.2 Sample Preparation

The single-pole, 20-amperes rated circuit breakers were purchased from Home Depot (model HOM120). All of the circuit breakers were installed in the testing stations to confirm that they were operational before exposure testing. All of the circuit breakers were removed from the stations, numbered, and chain-of-custody initiated. The baseline circuit breakers were put aside until needed. The test and control exposure testing was discussed in Section 4. Each run used seven circuit breakers. After a test or control circuit breaker set was prepared in the exposure chamber, the breakers were removed from the exposure chamber and visually inspected.

12.3 Circuit Breaker Testing Stations

After visual inspection, the breakers were installed in the testing station and observed for 90 days under load (Figure 12.1). The testing station is an electrical box containing 8 spaces, 16 circuits, 100 amp max from square D (Home Depot # 577-340). The circuit breaker box was wired with 12-gauge, 20-amp wire into the 120-V outlet. Each circuit breaker was wired in series with an electrical lamp (s513e) with an outlet box (s110e) manufactured by Thomas & Bretts (Home Depot # c214477 and b214426, respectively). Each lamp contained a Phillips 40-watt light bulb (Home Depot # a356140). The test or control circuit breakers were installed into slots 1 through 7, and the baseline circuit breaker was installed in slot 8 (Figure 12.1, upper left corner).

Figure 12.1 Circuit Breaker Test Stations



12.4 Results and Discussion

The circuit breakers were exposed to fumigant and visually inspected after removal from the exposure chamber. No visual damage was observed on any of the circuit breakers used in this program following fumigation. The circuit breakers were then installed into the testing stations for 90 days. The stations were observed on each work day and light bulbs replaced as needed. No breakers failed during the 90-day storage under load. Following the 90-day storage, the breakers were tested using current-time measurements done at 150% (30 amp) and 300% (60 amp) of the breakers' rated value. Tests were done using an AVO/multi-amp MS-2, available from Advanced Test Equipment Rentals. The test results are provided in Table 12.1. The circuit breaker data was statistically analyzed to determine whether the breaker was compromised after exposure to decontaminant by comparing the test results obtained with fumigant-exposed circuit breakers to those obtained with control coupons (not exposed to fumigant). Each breaker station contained one control breaker that had not been exposed in the chamber.

The measurement for the analysis was the time for the circuit breaker to open (Time-to-Open) when experiencing a current above its rated value. A circuit breaker that trips too quickly will protect personnel and equipment but can represent a significant loss of time and productivity for the users. A circuit breaker that takes too long to trip can result in a heat buildup, and possibly a fire, and might fail to protect equipment, users, and property.

A statistical analysis of the individual test results was conducted to detect potential statistical outliers (Q-test) and determine whether there were any differences (Welch's T-test) between the control circuit breakers and samples exposed to VHP. No statistical outliers were found in any of the data at the Q=0.99 level of confidence.

Table 12.2 summarizes the data for the average and standard deviation for the various test groups. The Welch's T-test was used with a 95% confidence level in order to determine whether the changes in the Time-to-Open between the groups were statistically significant. At the 30-amp challenge level, the slight

Table 12.1 VHP Circuit Breaker Test Results

4-hour VHP Box Test Control	60-Amp Test Time	30-Amp Test Time	4-hour VHP Test (250–300 ppm)	60-Amp Test Time	30-Amp Test Time
BN5022401	5.57	65.16	BV5051301	5.23	60.13
BN5022405	4.90	48.26	BV5051302	4.23	82.72
BN5022402	5.70	62.53	BV5051303	5.94	118.05
BN5022406	6.52	62.51	BV5051304	5.60	65.52
BN5022403	6.31	59.24	BV5051305	4.51	91.55
BN5022407	2.60	53.92	BV5051306	2.95	50.50
BN5022404	4.08	44.76	BV5051307	5.93	59.19
Baseline Breaker	4.96	40.94	Baseline Breaker	5.01	91.06
Test Average	5.10	56.63	Test Average	4.91	75.38
Standard Deviation	1.38	7.82	Standard Deviation	1.09	23.62
8-hour VHP Box Test Control	**60-Amp Test Time**	**30-Amp Test Time**	**8-hour VHP Test (125–150 ppm)**	**60-Amp Test Time**	**30-Amp Test Time**
BN5030801	5.75	67.61	BV5051201	2.44	64.80
BN5030802	5.92	43.72	BV5051202	4.28	79.00
BN5030803	5.14	49.62	BV5051203	4.60	57.23
BN5030804	6.39	70.91	BV5051204	3.62	55.94
BN5030805	5.90	56.40	BV5051205	3.30	84.22
BN5030806	5.69	69.43	BV5051206	4.66	60.63
BN5030807	5.06	57.39	BV5051207	2.51	58.90
Baseline Breaker	6.12	66.65	Baseline Breaker	3.03	49.96
Test Average	5.69	59.30	Test Average	3.63	65.82
Standard Deviation	0.46	10.45	Standard Deviation	0.93	11.25

increases in the Time-to-Open from the control to the VHP-exposed circuit breakers were not determined to be statistically significant. In addition, no difference was determined to exist at the 30-amp challenge between the 4-hour control and the 8-hour control.

However, under the 300% (60-amp) challenge, a statistically significant decrease in the Time-to-Open due to the 8-hour VHP exposure was observed. No difference was determined to exist between the control set and the 4-hour VHP exposed test group. While no difference was determined to exist between the 4-hour and 8-hour control groups, the Time-to-Open for the 8-hour VHP exposed group was statistically significantly different from the 4-hour VHP exposed group.

These results suggest that the longer exposure to the fumigant, even at lower concentration levels, did result in a statistically significant effect that became apparent at the higher (300% of rated value) test challenge. No specification was found to determine whether this effect was within the device failure criteria.

Table 12.2 Average and Standard Deviation by Group

Exposure	30-Amp Challenge Time-to-Open (sec)	60-Amp Challenge Time-to-Open (sec)
4-Hour Control	56.63 ± 7.82	5.10 ± 1.38
4-Hour @ 250 ppm VHP	75.38 ± 23.62	4.91 ± 1.09
8-Hour Control	59.30 ± 10.45	5.69 ± 0.46
8-Hour @ 125 ppm VHP	65.82 ± 11.25	3.63 ± 0.93

13.0 FTIR Analysis of Select Wood Samples

Using a Thermo-Nicolet Model 670 with Compact Parabolic Concentrator® (CPC) Diffuse Reflectance Accessory and a Mercury-Cadmium-Telluride Detector (HgCdTe), 12 wood coupons were tested for substructural oxidation. Samples were tested in the 5000–650 cm^{-1} range with 4 cm^{-1} resolution.

13.1 Sample Preparation

In August 2005, eight wood coupons were collected from the sample storage room. Coupons were prepared in order to show the cellular effects of exposure to VHP as compared to unexposed wood coupons and compared to unexposed coupons treated with liquid hydrogen peroxide.

Coupons WV5042509, WV5042609, WV5050909, and WV5051010 were exposed in the VHP chamber and allowed to age prior to FTIR testing.

Coupons WN5030409 and WN5060809 were not exposed to any hydrogen peroxide and were allowed to age prior to FTIR testing.

Coupons WN5030417 and WN5060817 were not exposed to VHP but were spiked with 0.5 mL of liquid hydrogen peroxide on one end of the coupon. During a 30-minute evaporation period, the liquid hydrogen peroxide was periodically stirred. After the 30 minutes, the coupons were blotted dry with Kimwipes®. These coupons were subsequently transferred to the FTIR for analysis.

13.2 FTIR

Twelve wood coupons were tested for substructural oxidation using a Thermo-Nicolet Model 670 with a CPC Diffuse Reflectance Accessory (Figure 1) and a Mercury-Cadmium-Telluride Detector. Instrument parameters were:

Spectral range	4000–650 cm^{-1}
Resolution	4 cm^{-1}
Scans	64
Apodization	Happ-Genzel
Phase correction	Mertz
Zero fill	2X
Final data spacing	2 cm^{-1}

Following preparation of the coupons, they were further prepared for analysis on the FTIR. Using 400-grit silicon carbide paper, the surface of the wood coupon was abraded. Sample sizes of less than 100 µg were collected. Samples were introduced to the Thermo-Nicolet Model 670 via the CPC Diffuse Reflectance Accessory.

13.3 Background and Analysis Method

The cellulose in wood is a linear polymer of β-(1,4)-D-glucopyranose (polysaccharide) units. This, as well as other polysaccharides with similar structures, provide the rigidity to wood. The effects of VHP on the polymer, if occurring, may be expected to result in cleavage of the chains at the C-O-C linkages, oxidation of the O-H functionalities to the respective carbonyl, and/or opening of the monomer rings. Expected effects in the infrared spectra of the wood are shifts and/or reductions in bands related to O-H and C-O-C, as well as increases in intensities of bands in the region of the spectra arising from C=O functional groups.

The effect of VHP on wood was investigated at the molecular level using diffuse reflectance infrared Fourier transform (DRIFT) spectroscopy. DRIFT is a technique in which the material to be investigated is diluted, after grinding or powdering, with a nonabsorbing material, for example, potassium bromide. A small quantity of the resulting mixture is placed in an accessory that allows the collimated infrared beam from the spectrometer to be focused on the surface of the material from above. Because the surfaces of the particles of analyte and diluent are oriented randomly, the infrared energy becomes decollimated, or diffused. The resulting spectrum is treated mathematically using the "Kubelka-Munk" transformation. The technique is used extensively in the pharmaceutical industry and in the analysis of agricultural products.

While a literature search has indicated that DRIFT may be expected to be useful for elucidating the effects of the VHP on wood, it may be difficult to prove a negative response of the wood to the VHP. For this reason, wood samples subjected to a more aggressive oxidation than would be expected during this test were also analyzed. Wood specimens (positive controls) exposed to liquid hydrogen peroxide (35%) and negative controls (no treatment) were prepared and analyzed in the same fashion as the test specimens.

The primary assumption of analysis was that the effects of exposure to hydrogen peroxide would oxidize the –OH in rings and ether linkages in the cellulose polymer of the wood. This would result in an increase in carbonyl bands noticeable in the 1700 cm^{-1} region. Normalization of samples were performed by analyzing the region around 2900 cm^{-1}. The ratio of CH stretching in this region can be compared to carbonyl stretching regions.

13.4 Results

Table 13.1 shows the integrated area responses for each sample in both the 2900 cm^{-1} and 1700 cm^{-1} regions analyzed. The ratio of the two regions is also provided. A discussion of the results can be found in section 13.5.

13.5 Discussion

Using the Welch's T-Test, no statistically significant differences were found between the control, VHP-exposed, or Liquid H_2O_2-exposed coupon sets. Analysis by this method did not reveal any changes to the structure of the wood due to oxidation by hydrogen peroxide (vapor or liquid).

Table 13.1 FTIR Analysis Data

VHP Exposed Coupons						
Sample ID	**WV5042509**	**WV5042609**	**WV5050909**	**WV5051010**	**Average**	**SD**
3025-2800	15.52	15.06	17.29	19.34	16.80	1.95
1824-1689	9.93	7.18	7.86	8.89	8.47	1.20
ratio	0.64	0.48	0.45	0.46	0.51	0.09
Control Coupons						
Sample ID	**WN5030409**	**WN5060809**	**WN5030417**	**WN5060817**	**Average**	**SD**
3025-2800	20.03	15.80	24.21	20.54	20.15	3.44
1824-1689	8.84	7.55	10.59	8.83	8.95	1.25
ratio	0.44	0.48	0.44	0.43	0.45	0.02
Liquid H_2O_2 Exposed Coupons						
Sample ID	**WN5030417**	**WN5060817**	**Average**	**SD**		
3025-2800	16.06	29.44	22.75	9.46		
1824-1689	7.31	12.13	9.72	3.41		
ratio	0.46	0.41	0.43	0.03		

14.0 Quality Assurance Findings

Two technical audits of the Instron destructive testing process on VHP-fumigated coupons were conducted over the course of the program. The first, conducted 6 June 2005, covered steel coupons from a control run in the VHP chamber. All operations were in accordance with the SOPs and IOPs. The second technical audit was conducted on 19 October 2005 and involved ceiling tile coupons. All operations were in accordance with the applicable SOPs and IOPs. Data quality audits were conducted on 7 of the 56 VHP material compatibility tests (13%). All were found to be acceptable, in accordance with the Quality Assurance Project Plan.

15.0 References

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Appendix A:
Coupon Identifier Code

All coupons were marked with an ID number that consisted of a nine-character alphanumeric code. A description of the identifier pattern and an example code are shown below.

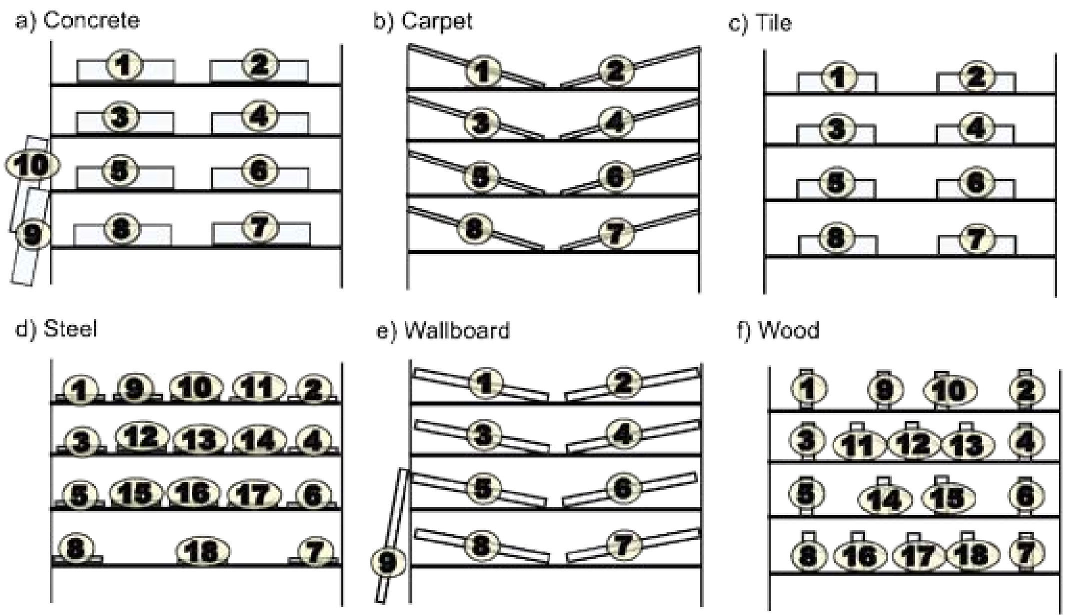
Code Pattern

Character	*Explanation*
1	Material
	W = wood
	G = gypsum
	S = A572 steel
	T = acoustic ceiling tile
	C = concrete cinder block
	R = carpet
	B = circuit breakers
	A = aluminum coupons
	F = copper coupons
	E = steel coupons
2	Fumigant
	V = VHP
	D = chlorine dioxide
	N = no fumigant
	Test start date
3	year for example: 4 = 2004
4,5	month for example: 06 = June
6,7	day for example: 10 = the 10th of a month
8,9	Chamber position (see IOP DS04016 Figure 1)

Example GV4101104

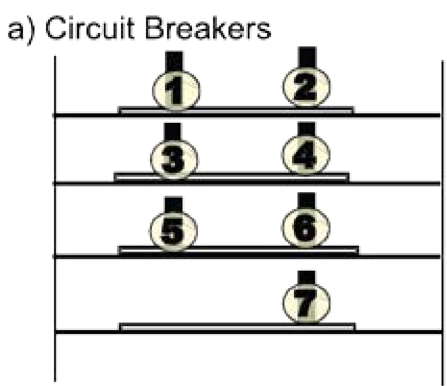
Gypsum wallboard with test start date of October 11th, 2004; sample number 4.

Figure A-1: IOP DS04016 Figure 1, “Coupon Placement in Chambers”



Coupons shown on rack shelves from direction of glove box transfer chamber. Pictoral coupon scaling for length and width is (0.75 * 2 *(cm / 10)).

Figure A-2: IOP DS04016 Figure 2, “Circuit Breaker Placement in Chambers”



Coupons shown on rack shelves from direction of glove box transfer chamber.

Appendix B:
Detailed Coupon Preparation and Inspection Procedures

Coupon Preparation Procedure

The coupon preparation, unless otherwise noted, was conducted at the Edgewood Chemical Biological Center Experimental Fabrication Shop.

Mechanically Graded Lumber (Bare Wood)

- Stock Item Description: 2 x 4 x 8 KD WW/SPF Stud
- Supplier/Source: Home Depot, Edgewood Maryland
- Coupon Dimensions: 10 in. x 1 ½ in. x ½ in.
- Preparation of Coupon:
  - The machined ends of the stock were discarded by removing > ¼ in. of the machined end. Coupons were cut from stock, using a table saw equipped with an 80-tooth crosscut blade.

Latex-Painted Gypsum Wallboard

- Stock Item Description: ½ in. 4 ft. x 8 ft. Drywall
- Supplier/Source: Home Depot, Edgewood Maryland
- Coupon Dimensions: 6 in. x 6 in. x ½ in.
- Preparation of Coupon:
  - The ASTM method requires that the samples be taken from the interior of material rather than from the edge (machined edge). The machined ends of the stock were discarded by cutting away > 4 inches from each side.
  - Coupons were cut from stock, using a table saw equipped with an 80-tooth crosscut blade.
  - The 6 in. x 6 in. coupons were painted with 1 mil of Glidden PVA primer and followed by 1–2 mils of Glidden latex topcoat. The primed coupons were allowed to stand for > 24 hours prior to the application of the topcoat.
  - All six sides of the 6 in. x 6 in. coupon were painted.

Concrete Cinder Block

- Stock Item Description: 8 in. x 16 in. x 1.5 in. concrete cinder block cap
- Supplier/Source: York Supply, Aberdeen Maryland
- Original Coupon Dimensions: 4 in. x 8 in. x 1.5 in.
- Modified Coupon Dimensions: 4 in. x 8 in. x 0.5 in.
- Preparation of Coupon:
  - Coupons were cut from stock using a water-jet.
  - Four coupons were cut from each stock piece.
  - Original dimensions were too large for material testing.
    - Each coupon was cut into three sections.
    - Two sections were measured at modified coupon dimensions.
    - The third section was discarded.

Carpet

- Stock Item Description: 12-ft. Powerhouse 20 Tradewind
- Supplier/Source: Home Depot, Edgewood, Maryland
- Coupon Dimensions: 6 in. x 8 in.
- Preparation of Coupon:
  - Coupons were cut from the stock using a utility knife.
  - The longer direction (8 in.) was cut parallel to the machine edge.
  - The machined edge was discarded by removing > ½ in.

Painted Structural Steel

- Stock Item Description: A572 Grade 50, 4 ft. x 8 ft. x ¼ in.
- Supplier/Source: Specialized Metals
- Coupon Dimensions: 1/4 in. x 12 in. total, dog bone shaped with 2 in. wide at ends, ¾ in. wide at center
- Preparation of Coupon:
  - Coupons were cut from stock using a water-jet.
  - A visual observation was conducted on each coupon to determine whether size and shape had deviated from dimension. If so, the coupon was discarded.
  - Coupons were cleaned and degreased following procedures outlined in TTC-490.
  - Coupons were prepared for painting per TT-P-645 with red oxide primer.

  The Edgewood Chemical Biological Center Experimental Fabrication Shop prepared the materials in accordance with the standards used for the preparation and painting of steel. TTC-490 is a federal standard providing cleaning methods and pretreatment for iron surfaces for application of organic coatings. The pretreatment is the application of a zinc phosphate corrosion inhibitor. TT-P-645 is a federal standard for the application of alkyd paint. These standards were not obtained through this program but were purchased by the shop for their work.

Ceiling Suspension Tile

- Stock Item Description: Armstrong 954, Classic Fine Textured, 24 in. x 24 in. x 9/16 in.
- Supplier/Source: Home Depot, Edgewood, Maryland
- Coupon Dimensions: 12 in. x 3 in. x 9/16 in.
- Preparation of Coupon:
  - Coupons were cut from stock, using a table saw equipped with an 80-tooth crosscut blade.
  - Sixteen samples were removed from each stock item.

Coupon Inspection Procedure

All coupons were inspected prior to testing to ensure that the material being used was in suitable condition. Coupons were rejected if there were cracks, breaks, dents, or defects beyond what are typical for the type of material. In addition, coupons were measured to verify the coupon dimensions. Coupons deviating from the dimension ranges listed below were discarded.

Mechanically Graded Lumber (Bare Wood)	10 in. ± 1/16 in. x 1.5 in. ± 1/16 in. x 0.5 in. ± 1/32 in.
Latex-Painted Gypsum Wallboard	6 in. ± 1/16 in. x 6 in. ± 1/16 in. x 0.5 in. ± 1/16 in.
Concrete Cinder Block	4 in. ± ½ in. x 8 in. ± ½ in. x 0.5 in. ± 1/16 in.
Carpet	6 in. ± 1/8 in. x 8 in. ± 1/8 in.
Painted Structural Steel	1/4 in. ± 1/128 in. x 12 in. ± 1/16 in. with 2 in. ± 1/16 in. wide at ends, ¾ in. ± 1/16 in. wide at center
Ceiling Suspension Tile	12 in. ± 1/8 in. x 3 in. ± 1/16 in. x 9/16 in. ± 1/16 in.

Appendix C:
Wood Coupon Location of Break

The ASTM test method requires reporting the location of the break for each wood sample. The purpose of this appendix is to provide this reporting information in pictorial form. Yellow arrows are used on samples where the photograph contrast may not clearly show the location of the break.

Figure C-1: Location of Break, Wood Coupons – VHP Control Set

Figure C-2: Location of Break, Wood Coupons – VHP 125 – 150 ppm Set

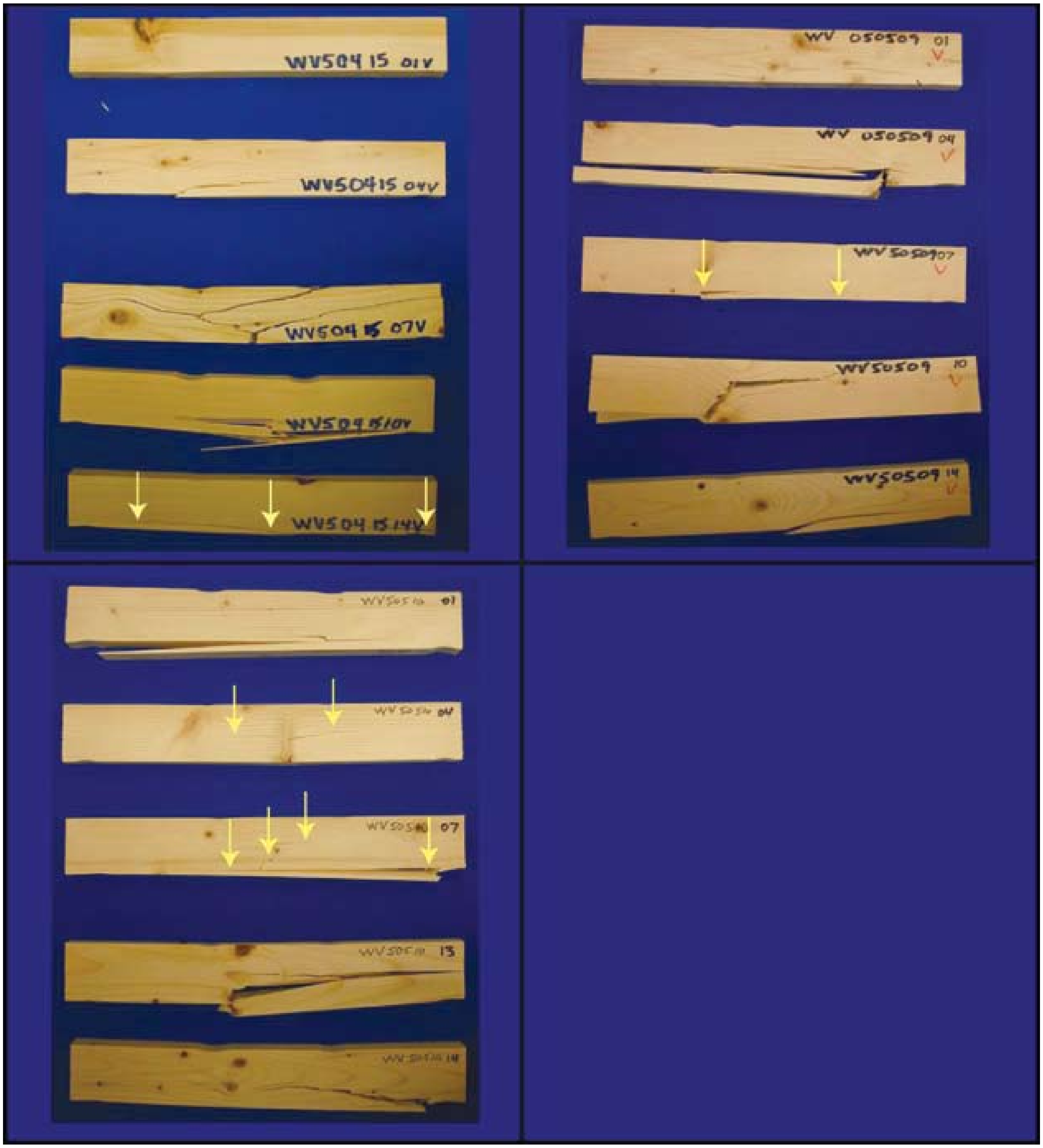
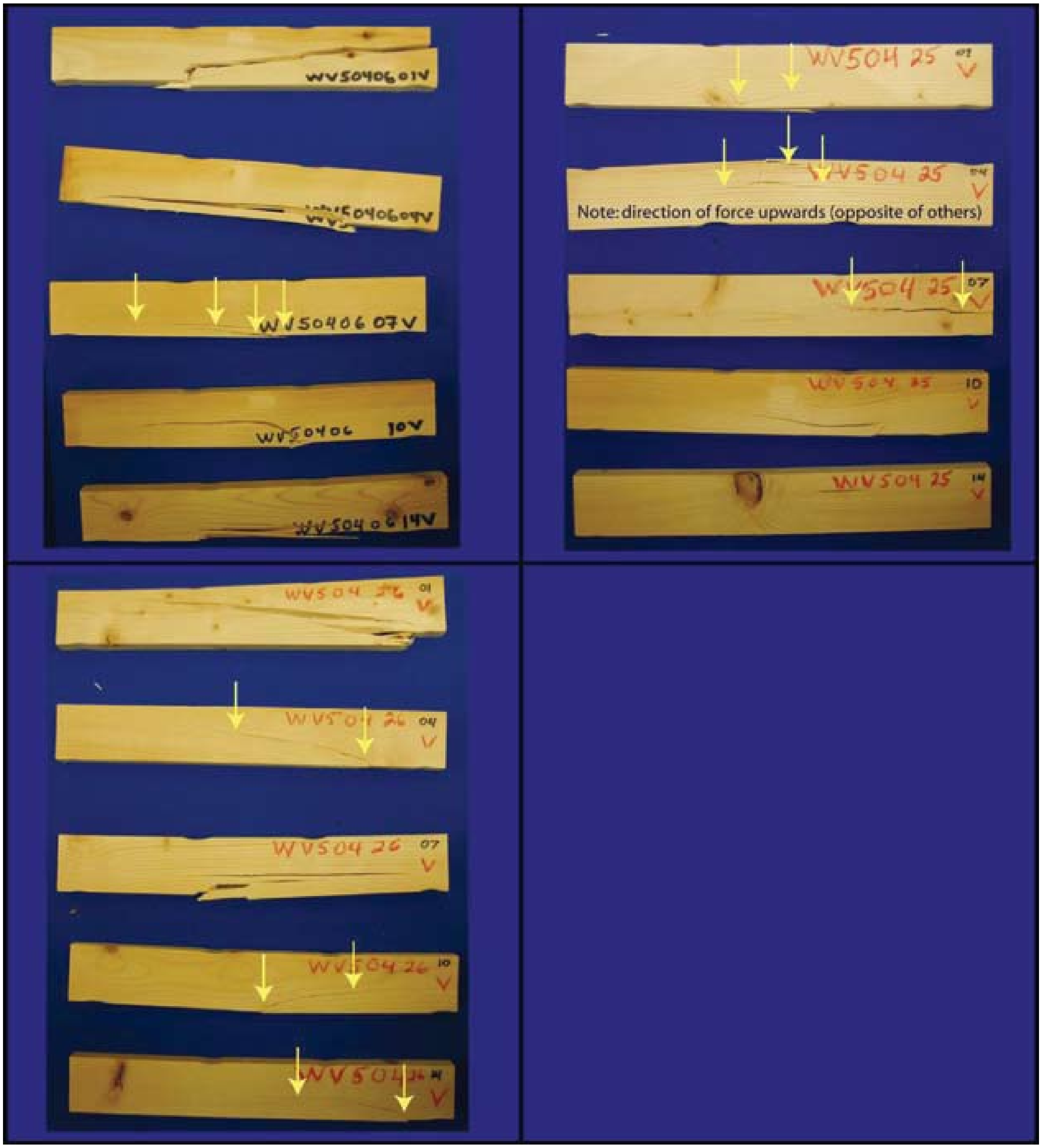


Figure C-3: Location of Break, Wood Coupons – VHP 250 – 300 ppm Set



Appendix D:
Concrete Cinder Block Coupon Break Location

The location of the break for each concrete sample is reported here, from the testing using ASTM Test Method C140-03. The purpose of this appendix is to provide this reporting information in pictorial form. Yellow arrows are used on samples where the photograph contrast may not clearly show the location of the break.

Figure D-1: Location of Break, Block Coupons – Control Set

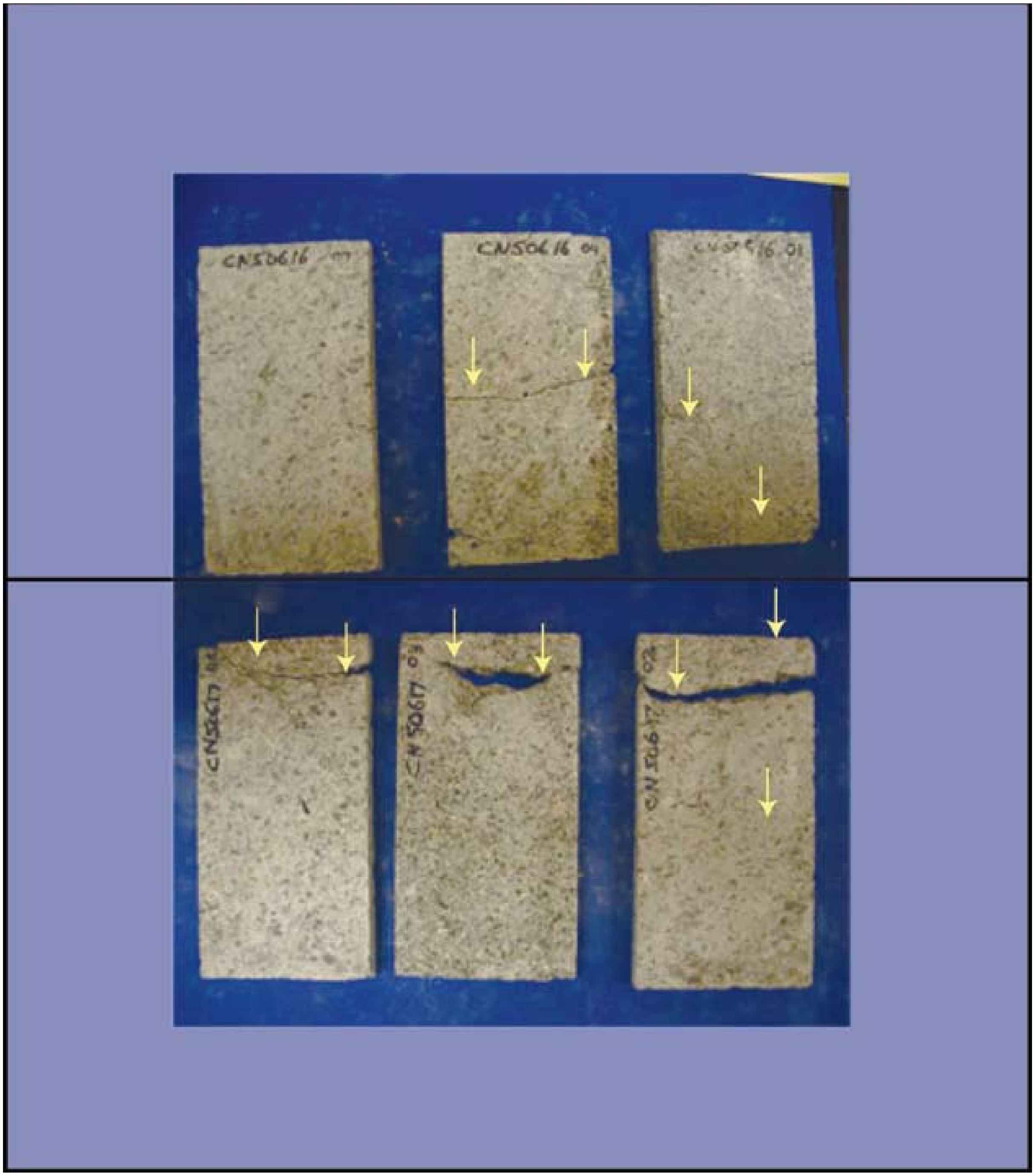


Figure D-2: Location of Break, Block Coupons – VHP 125 – 150 ppm Set

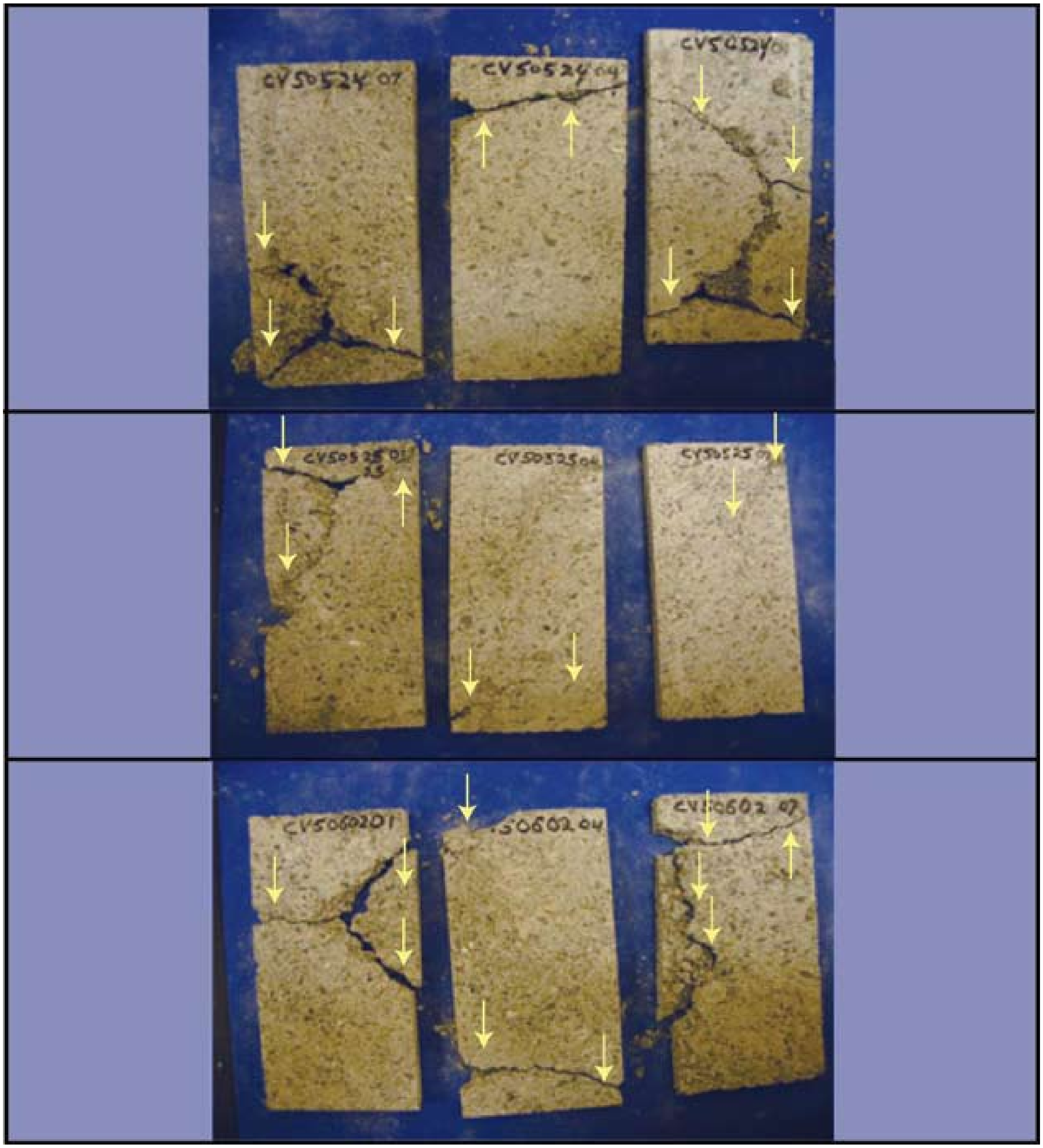
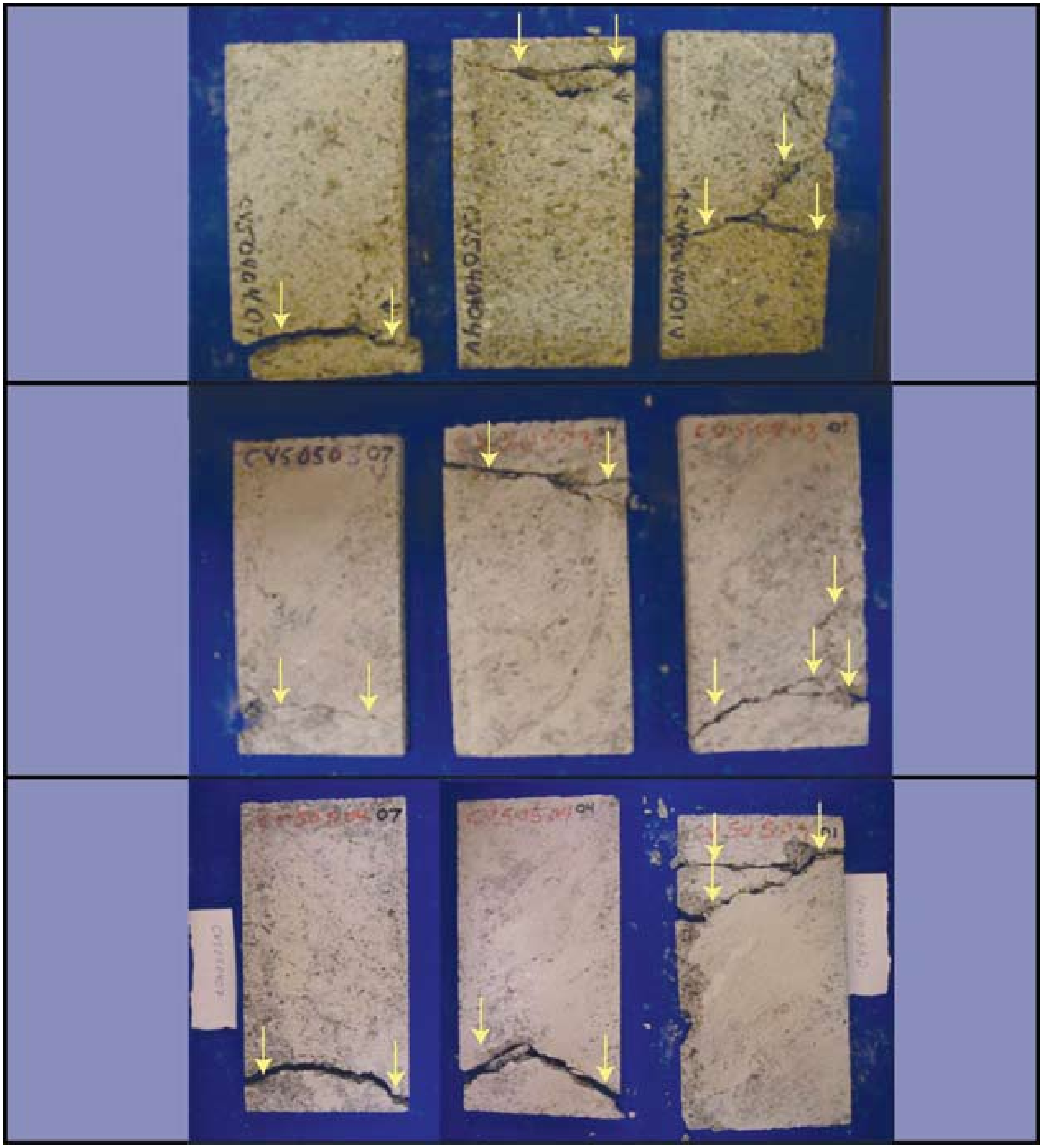


Figure D-3: Location of Break, Block Coupons – VHP 250 – 300 ppm Set



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