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Workplace Simulations: An Alternative to On-Site Industrial Hygiene Sampling

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Numerous hazardous agents are present in the workplaces of the construction industries. Conducting an on-site industrial hygiene survey in some phases of these industries can be difficult, if not impossible. An example is the evaluation of hazards arising in the cutting of epoxy-coated steel reinforcing rod (coated rod) in the structural steel erection industry (SIC 1791). When necessary, coated rod is cut using either a gasoline-powered cut-off saw or an oxy-acetylene cutting torch. Using either method generates smoke and dust that may be hazardous in their own right or that may contain hazardous materials such as combustion products of the epoxy resin coating. Typically, cutting coated rod is an unscheduled event that may have to be done quickly, as this phase of construction usually involves pouring large volumes of fresh (wet) concrete. It is not practical to anticipate such an event and to have industrial hygiene personnel and equipment standing by on-site to perform necessary industrial hygiene sampling. This article presents techniques used to address this problem by conducting an industrial hygiene evaluation of these work activities at a simulated work site. Results are presented documenting that a simulated work site can be effectively used to circumvent the problem of performing industrial hygiene sampling of an inaccessible work site. Venable, H.L.; Esswein, E.J.; Tharr, D.G.; Brightman, H.S.: *Workplace Simulations: An Alternative to On-Site Industrial Hygiene Sampling*. *Appl. Occup. Environ. Hyg.* 9(8):545-551; 1994.

Introduction

Numerous hazardous agents and working conditions are encountered in the workplaces of the construction industry. Conducting on-site industrial hygiene sampling to evaluate hazardous agents and working conditions in some phases of these industries can be difficult, if not impossible. Such was the case in responding to a request submitted to the National Institute for Occupational Safety and Health (NIOSH) to conduct a health hazard evaluation (HHE) of potential hazards and working conditions in the cutting of epoxy resin-coated steel reinforcing rod (coated rod) in the structural steel erection industry.

As a part of its legislative mandate, NIOSH is directed to conduct HHEs in the workplace as may be requested by employees, employee representatives, or employers.⁽¹⁾ An HHE involves studying a workplace, including the use of industrial hygiene sampling, to determine if there is a health hazard to employees caused by exposure to hazardous materials.⁽²⁾ The workplace may be a particular department within a factory or industrial plant or may include the entire facility.

In responding to the HHE request to evaluate potential hazards in the cutting of coated rod, NIOSH found it difficult to organize and complete industrial hygiene sampling of an actual work site involving these activities. The cutting of coated rod is quite often an unscheduled event in the construction process. It was not practical to have industrial hygiene personnel and equipment on a stand-by basis at a work site to conduct sampling in the event coated rod was cut. Further, the pouring of large volumes of fresh (wet) concrete may also be involved in these activities. The concrete must be poured quickly, making it difficult, if not impossible, to conduct industrial hygiene sampling of the work site.

One solution to the problem presented to NIOSH was to create a simulated work site at which industrial hygiene sampling could be conducted. Use of the simulated work site permitted researchers to control the time and accessibility to cutting operations required to conduct industrial hygiene sampling. The purpose of this article is to describe the methods used to create and sample the simulated work site. Results of sampling are also briefly presented to demonstrate the effectiveness of this technique, but are available in more detail elsewhere.⁽²⁾

Methods

Description of Work Activity

Concrete structures typically are reinforced with the use of steel reinforcing rods. Selection of size of rods is based on structural strength, design, and load-bearing requirements. Rods are tied together using steel wire and then placed in

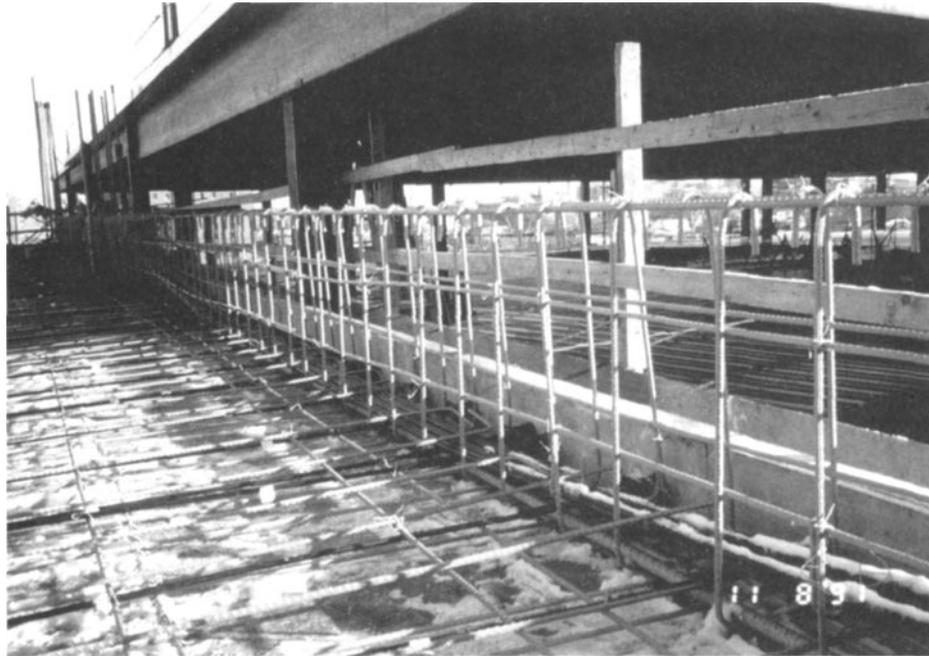


FIGURE 1. Epoxy-coated steel reinforcing rod bent and wired into position prior to pouring of concrete.

excavated areas or forms into which concrete is poured (see Figure 1). The reinforcing rod is totally encased in concrete unless additional rod is to be connected and the process continued, in which case a portion of the rod is left protruding out of the concrete to make these connections. The final pouring of concrete usually completes the encapsulation of the rod.

Steel reinforcing rod coated with epoxy resin (coated rod) is most often used in concrete structures exposed to the weather. Examples of such structures include multi-level parking garages, bridges, and road surfaces. The epoxy coating prolongs the life of the rod by minimizing corrosive chemical action between the steel and encasing concrete. To a lesser extent, the epoxy coating also minimizes corrosive chemical action from extraneous sources such as salt used to de-ice parking lot surfaces and roadways.

For economical reasons and to expedite construction, rod is usually supplied already cut to length, bent to shape if specified, and coated with epoxy resin by the manufacturer. Rod cutting may or may not be necessary in certain phases of construction. Rod may need to be cut as a result of changes or errors in design, encountering of unexpected obstacles in construction, or mistakes in the placement of reinforcement. Need for rod cutting in these instances is usually an unplanned event that may need to be done very quickly because the pouring of large volumes of fresh (wet) concrete may be involved.

When necessary, rod (coated or uncoated) is cut using either a gasoline engine-powered cut-off saw fitted with a cutting wheel or an oxyacetylene cutting torch (see Figures 2 and 3). Smoke, and possibly fumes, are observed during the cutting operations on coated rod using either method.

In some instances, the rod is welded together, also generating smoke and fumes. Welding activities were not included in this evaluation.

In all cases where the epoxy coating has been burned or scraped away, an epoxy paint "patch kit" is used to recoat the exposed metal surface. Essentially, this process consists of hand-painting the exposed areas with the epoxy paint. The patch kit used in this evaluation comes in two parts that are mixed just prior to use. Painting may also produce potentially hazardous agents arising primarily from solvents used in the epoxy paint.

On-Site Surveys

Two on-site visits were made to actual construction sites to obtain essential information in designing a simulated work site, as well as the sampling protocol for conducting the evaluation at a simulated work site. One site visit was conducted during the construction of a multilevel parking garage. The other site visit was conducted during the construction of a road surface for an on/off ramp to an interstate highway. From this information, a determination was made that sampling should be done for unenclosed and enclosed working spaces. A considerable amount of coated rod is cut in enclosed work areas such as excavations.

Description of the Simulated Work Site

A simulated work site was erected out-of-doors on the grounds of a vocational school in the Park Hills, Kentucky, area. Coated rod, 5/8-inch in diameter except as noted, was tied together in various configurations similar to those used at an actual construction site. These configurations included steel reinforcing rod tied into "mats" and placed parallel to the ground as would be done during construc-

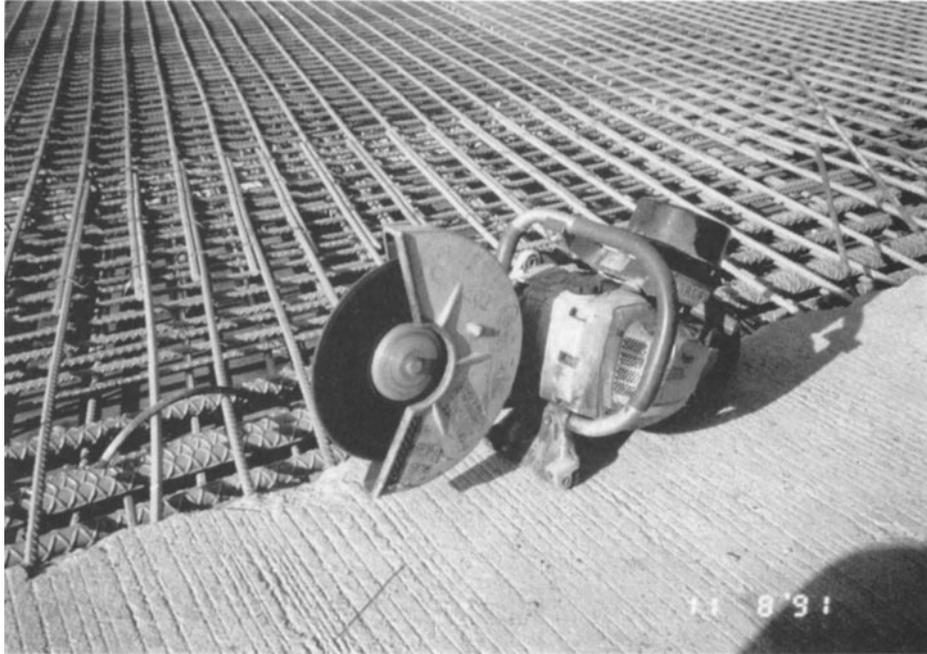


FIGURE 2. Gasoline-powered cut-off saw used in cutting epoxy-coated steel reinforcing rod.

tion of concrete slabs or decks. Other configurations simulated tied vertical structures such as columns or parapet walls. Larger diameter (>1-inch, as compared to the more commonly used 5/8-inch) coated rod was configured into reinforcing structures used in the construction of footers, the lowest structural elements that support most of the structure's weight.

An apprentice iron worker volunteered to perform all

cutting and painting operations involved in the HHE. For reasons of safety, and to ensure a representative sampling environment, the apprentice iron worker performed all cutting activities under the direct supervision of an experienced iron worker. Further, the condition and operation of all equipment used were also under the direct supervision of the experienced iron worker.

To simulate an enclosed working space that might be



FIGURE 3. Oxy-acetylene cutting torch being used to cut epoxy-coated steel reinforcing rod.



FIGURE 4. Plywood panels and framing supports used to simulate an enclosed work space.

found at an actual construction site (for example, excavated trenches), plywood panels and framing supports made from two-by-four lumber were placed horizontally around the simulated work site and nailed together (see Figure 4). The top of the enclosure was left open.

Prior to cutting operations, the volunteer iron worker was fitted with a powered air-purifying respirator (PAPR) fitted with a combination organic vapor and high efficiency particulate air filter to protect against potential airborne hazards. Sampling pumps were also placed on the iron worker prior to cutting operations to conduct personal breathing zone sampling. Sampling was conducted throughout the exercise with the intent to approximate an 8-hour work shift as closely as possible.

Hazardous Agents Selected for Sampling

Hazardous agents were selected for sampling on the basis of information available in material safety data sheets

provided for the coated rod and the patch kits used in painting operations. Sampling of products of combustion resulting from cutting coated rod was determined on the basis of information provided in material safety data sheets, as well as from an unpublished report presenting some results of industrial hygiene sampling of rod-cutting activities.⁽³⁾

Because of the numerous potential chemical hazards possible, the sampling protocol was designed as a screening process rather than an in-depth sampling procedure. Low concentrations of chemicals were anticipated, particularly carbon monoxide, based on the previous research.⁽³⁾ As a result, maximum flow rates as recommended by NIOSH were used for each sampling procedure requiring the use of a personal sampling pump.⁽⁴⁾ In addition to sampling for organic compounds with standard charcoal media, a qualitative thermal desorption method was also used to determine the presence, but not the amount, of or-

TABLE I. Sampling and Analysis Techniques

Substance	Collection Media	Flow Rate	Analytical Method
Total particulate	Prew weighed polyvinyl chloride filters	1.5 L/min	NIOSH Method 0500
Metals	Polyvinyl chloride filters	1.5 L/min	NIOSH Method 7300
Oxides of nitrogen	Palmer tubes	Passive diffusion	NIOSH Method 6700
Aldehydes	Orbo 42 sampling tubes	50 cc/min	NIOSH Method 2539
4,4' Methylene dianiline	Acid-treated glass fiber filter	3 L/min	NIOSH Method 5029
Volatile organic compounds	Charcoal tubes	200 cc/min	NIOSH Method 1501
Carbon monoxide	carbotrap thermal tubes	50 cc/min	thermal desorption
	Draeger model 190 data logger monitor		Direct reading instrument

ganic compounds. As presented in Table I, agents sampled for during cutting operations included total particulates, metals, oxides of nitrogen, aldehydes, 4,4' methylene dianiline, volatile organic compounds, and carbon monoxide. Direct reading instruments and length of stain detector tubes were used to sample for nitrogen oxide gases, formaldehyde, and carbon dioxide.

The ends of coated rod exposed by cutting operations were painted with an epoxy paint using a 3-inch-wide paintbrush. Rods were oriented in both the vertical and horizontal positions as they were painted. Both standard charcoal media and a qualitative thermal desorption method were used to sample for methyl isobutyl ketone, xylene, and 2-butoxyethanol.

Results

The use of the simulated work site proved to be effective in evaluating hazards arising from the cutting or painting of epoxy-coated steel reinforcing rod.

Sampling data indicated no exposures of concern to oxides of nitrogen, aldehydes, 4,4' methylene dianiline, or volatile organic compounds that could be directly attributable to the epoxy resin coating on the rods or decomposition of the resin during cutting operations. Similarly, no excessive exposures of concern to methyl isobutyl ketone, xylene, or 2-butoxyethanol were identified during simulation of the use of the epoxy patch kit in painting operations. However, overexposure to total particulates when using

the cut-off saw was documented. A total particulate concentration of 19.43 mg/m³ was measured during cutting operations using the cut-off saw. This level exceeds the Occupational Safety and Health Administration (OSHA) permissible exposure level (PEL) of 15 mg/m³ for total particulate.⁽⁵⁾ In addition, these emissions were found to contain the toxic metals presented in Table II. Inductively coupled argon plasma analysis (NIOSH Method 7300) of total particulate samples revealed concentrations of 6.268 mg/m³ iron [NIOSH recommended exposure level (REL), 5 mg/m³], 0.146 mg/m³ copper (NIOSH REL, 0.1 mg/m³), 0.034 mg/m³ nickel (NIOSH REL, 0.015 mg/m³), 0.023 mg/m³ titanium (NIOSH REL, lowest feasible level), and 0.009 mg/m³ arsenic (NIOSH REL, 0.002 mg/m³).⁽⁶⁾

A total particulate level of 10.83 mg/m³ measured during cutting operations using the cutting torch did not exceed the PEL of 15 mg/m³. However, these emissions were also found to contain toxic metals (see Table II).

Although the OSHA 8-hour time-weighted average of 50 ppm for carbon monoxide was not exceeded, peak exposures as high as 346 ppm were correlated with the use of the gasoline-powered cut-off saw exceeding the OSHA ceiling exposure concentration of 200 ppm for carbon monoxide.⁽⁵⁾

Discussion

Simulated working conditions or environments for testing or evaluating protective equipment, work practices, or

TABLE II. Metals Data

Element	Sample Description ^A						
	Cut-Off Saw		Cutting Torch		NIOSH REL (mg/m ³)	OSHA-PEL ^C (mg/m ³)	ACGIH TLV (mg/m ³)
	Sample (mg/m ³)	MDC ^B	Sample (mg/m ³)	MDC			
Aluminum	0.205	0.006	ND ^D			15.00	10.0
Arsenic	0.009	0.006	ND		0.002 CL	0.01	0.2
Barium	0.002	0.001	ND		0.5	0.5	0.5
Chromium	0.009	0.001	0.023	0.005	0.5	0.5	0.5
Copper	0.108	0.001	0.146	0.005	0.1	0.1 (fume, dust)	1.0
Iron	6.268	0.001	6.042	0.001	5.0	10.0 (fume)	5.0
Lead	0.011	0.003	0.031	0.010	<0.1	0.05	0.15
Magnesium	0.011	0.003	0.038			15.0	10.0 (fume)
Manganese	0.051	0.001	ND	0.005	1.0 3.0 STL	5.0 CL (fume)	5.0 (dust)
Molybdenum	0.006	0.001	0.034	0.005	10.0	15.0 (insol)	
Nickel	0.0245	0.001	ND	0.005	0.015	1.0	1.0
Thallium	0.031	0.009	0.014		0.1	0.1 Sk	0.1 Sk
Titanium ^E	0.023	0.001	0.031	0.031	F	15.0	10.0
Zinc	0.009	0.003	ND	0.010	5.0	15.0	10.0
Zirconium	0.005	0.001	ND		10.0 STL		10.0 STL

^ASample volume was 351 and 96 L of air for the cut-off saw and oxy-acetylene cutting torch, respectively.

^BMDC, minimum detectable concentration.

^CSee ref 5.

^DNot detected.

^EExposure data reported for the metal oxide.

^FLowest feasible concentration.

CL = ceiling; STL = short-term exposure limit; Sk = skin; insol = insoluble; no values given for REL indicates none stated at this time; all other values presented are expressed as 8-hour time-weighted averages; TLV = threshold limit value.

engineering controls have been used when it was not convenient or practical to conduct testing or evaluation in the actual workplace.⁽⁷⁻¹⁰⁾

Pertinent to this research is the use of simulated work sites or working conditions in the evaluation of workplace hazards. Using a simulated work site as presented here permitted control of the type and duration of work activity to be sampled, as opposed to being subject to limitations that would have been encountered at an actual construction site.

It also permitted timely access to both the worker and the working environment in order to accomplish sampling of selected hazards. This was particularly advantageous in conducting sampling with direct reading instruments such as length-of-stain tubes that, in this instance, required near source point sampling because of anticipated low concentrations of chemicals that may have been present. Because there were no time constraints, sampling using direct reading instrumentation was accomplished with greater frequency and flexibility than would have been possible, if at all, at an actual construction site.

Sampling the simulated work site was accomplished with minimal difficulty. Although use of a simulated work site provided better access to the worker for conducting breathing zone sampling, the problem of access persisted when sampling with direct reading instruments or detector tubes in simulated enclosed spaces. As would most likely be the case on an actual construction site, there was not enough room for both the iron worker and the industrial hygienist in the enclosed space, making it difficult to conduct sampling in these instances. The simulated work site permitted such sampling by allowing the industrial hygienist to lean over a wall of the simulated enclosure and placing the probe or sampling tube as close as possible to the desired sampling location (see Figure 3). This may not have been possible at an actual construction site.

The numerous, potentially hazardous, exposures involved in epoxy resin-coated rod-cutting operations were not well defined. Therefore, it was desirable to evaluate as many potentially hazardous exposures as possible. Consequently, in addition to the PAPR respirator, the volunteer iron worker was simultaneously fitted with several pumps and sampling trains. Such extensive use of sampling equipment may not have been possible on an actual construction site. Further, frequent access to pumps and sampling trains was an advantage in using the simulated work site. One equipment check revealed that a pump had faulted. This incident may not have been noticed as quickly if it had occurred at an actual construction site because of limited access to the worker, and may have resulted in a loss of sampling data.

The degree of flexibility in controlling the work environment that is possible through the use of simulated work sites can provide for a broader exposure assessment. In designing the sampling protocol of follow-up evaluations, emphasis can be placed on the quantitative identification of hazardous agents and measurement of potential exposures identified in the initial exposure assessment. As an

example, results of sampling of potentially hazardous exposures in cutting operations reported here indicate that the scope of subsequent evaluations should be focused on the generation of total particulates, to include toxic metals, and elevated levels of carbon monoxide. Further investigation of possible differences in the rate and total accumulation of particulates between unenclosed and enclosed work spaces, concentration of respirable as opposed to total dust concentrations, and the efficacy of using personal protective equipment to reduce exposure to hazards in performing these work activities should also be considered. Additional research should include an assessment of exposure to noise in operating the gasoline-powered cut-off saw. If possible, this research should be conducted at an actual construction site to evaluate actual working conditions.

In using simulated work sites for exposure assessment, it is important to be aware of the need to achieve a simulated work environment as representative of the actual work site as possible. It is necessary to be aware of any (actual) site-dependent factors or other factors that may bias results obtained in the use of simulated work sites. In the case presented here, it was not possible to duplicate the occurrence of other hazardous agents or conditions that occur at an actual construction site. For example, potential exposure to other hazardous agents such as silica in dust arising from the presence of on-going or already completed concrete work could not be duplicated at the simulated work site. Despite these limitations, it is the opinion of the authors that, in some instances, the use of a simulated work site is an efficient way to conduct initial exposure assessments.

Disclaimer

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