A Case Study of Real-Time Exposure Training in Construction

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Abstract

Current technology exists in roadway construction to control respirable dust and silica exposure for many tool-specific applications, but under-utilization of dust suppression systems and a lack of tool-specific training are leading to unnecessary exposure within the industry. A case-study of cut-off saws in roadway construction was performed 1) to collect and evaluate real-time inhalation exposure data for a silica-producing operation, 2) to create training materials using a side-by-side visual comparison of known dust control options, and 3) to survey construction supervisors in regards to the effectiveness and usability of the training materials produced from this assessment.

A real-time aerosol monitor was used to measure respirable dust levels during concrete cutting, revealing a respirable dust reduction of 80.9\% for wet suppression (n=3) and 78.6\% for local exhaust ventilation (LEV) (n=3) when compared to cutting without dust control (n=3). A task-based analysis of each dust control determined that these controls were less effective during vertical cuts versus flat cuts (i.e. 67\% less effective for LEV controls and 76\% less effective for wet suppression). Best work practices were derived from this data along with real-time side-by-side exposure videos of each control method, which were then compiled into tool-specific training materials. Construction supervisors (116) at a local contractor were trained using these materials, followed by a 27 question survey regarding the effectiveness of this training. Of the 101 returned surveys, 85\% of supervisors answered “yes” when asked if they would consider changing current uncontrolled work practices after receiving the training.

Keywords: Construction, Training, Silica, Quartz

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1. Introduction

Crystalline silica is a constituent of many common building materials such as concrete, stone, and masonry (NIOSH, 2002; OSHA, 2008). Manipulation of these building materials during construction and demolition generates airborne crystalline silica particles (OSHA, 2008). Inhalation of respirable-size, silica particles is a causal agent of progressive lung fibrosis, lung cancer, and other serious autoimmune diseases (NIOSH, 2002; IARC, 1997). According to the World Health Organization (WHO), thousands still die annually from these exposures (WHO, 2000). In 2009, the Occupational Safety and Health Administration (OSHA) released a guidance document regarding known control options for tool-specific operations in construction including cutting, grinding, hammering, and drilling (OSHA, 2009). The latest National Occupational Research Agenda (NORA) agenda for construction has requested research to explore methods to “increase awareness about silica hazards and known solutions among construction workers, contractors, owners, and suppliers” (NIOSH, 2007). The objectives of this case study were 1) collect and evaluate real-time dust exposure data during hand-held concrete cutting, 2) create training materials using a side-by-side visual comparison of known dust control options for hand-held saws, and 3) survey local construction supervisors in regards to the effectiveness and usability of the training materials produced from this assessment.

2. Background

Cutting concrete produces elevated levels of respirable dust containing crystalline silica (Croteau et al., 2002; Flanagan et al., 2006; Thorpe et al., 1999). Silica-related lung diseases are completely preventable by controlling inhalation exposure (OSHA, 2008). Engineering controls such as wet suppression and local exhaust ventilation (LEV) are preferred over administrative control and respiratory protection because they reduce exposure at the source (AIHA, 2003). More importantly, a survey conducted in the U.S. indicated that less than 45 percent of construction contractors require respiratory protection during the course of work (U.S. Bureau of Labor Statistics, NIOSH, 2003).

“The workers’ knowledge of risks associated with their tasks, and perhaps more importantly, how these risks can be controlled, is essential to improve their health” (Rosen et al., 2005). Video exposure monitoring (VEM) combines video footage of a process familiar to the worker with the corresponding instantaneous measurements of exposure. VEM can be used to show workers or management where exposures occur and how they can be controlled (McGlothlin, 2005). Research regarding the application of VEM techniques in construction has been limited, with even less research evaluating the effectiveness of these techniques as a component of training.
3. Materials and Methods

In this case study, real-time exposure monitoring was performed during the cutting of expansion joints in concrete curbs. The study evaluated exposure during hand-held cutting without dust control and with two exposure control methods; wet suppression and local exhaust ventilation. Personal real-time respirable dust monitoring was accomplished using one DustTrak real-time aerosol monitor (model 8520; TSI, Inc.) in conjunction with a 10 µm inlet adapter connected to a 10 mm nylon Dorr-Oliver cyclone. The aerosol monitor was zeroed before calibration, and pre-calibrated to a flow rate of 1.7 liters per minute. The operator wore the monitor on his lower back with the cyclone placed on the left lapel. Before the commencement of each sampling period, the time on the DustTrak was synchronized with the time on a site laptop and filmed with a video recorder (Rosen et al., 2005). Respirable dust concentrations were then logged every second for the duration of each sampling period.

Three saw joints were cut consecutively by the operator to assess dust concentrations as the process progressed. Three consecutive samples were collected for each exposure control method on the same length of curb within a two hour time period. After the data was collected, the individual video frames were analyzed with the real-time exposure concentrations using the reference time filmed at the beginning of each sample. The real-time exposure videos were rendered using Adobe Photoshop CS4 and Microsoft Visual Basic v6.5 in Microsoft Excel. Video from one sample for each exposure control method was rendered into a video with a graph of the streaming concentration below the camera footage. A combined side-by-side video was also created using the individual rendered videos for all three control options. The cutting process was then broken into 10 individual subparts, which were then assessed individually for both peak concentration and exposure contribution (See Table 1). For each exposure control method, peak exposure was expressed as the median concentration of the individual peak sample concentrations and mean concentration was expressed as the overall or grand mean of the individual mean sample concentrations.

After the exposure assessment was complete, a tool-specific training presentation was developed using these results. Construction supervisors (116), employees of a local roadway construction contractor, were trained using the materials as a component of an internal annual safety refresher. The presentation was followed immediately by an anonymous 27 question survey regarding the effectiveness of the training and its components. The 15 minute training presentation first included a brief introduction to silica, a video of the process without control (video 1), a video rendered with real-time exposure for the process without control (video 2), and a side-by-side video rendered with real-time exposure for each control option (video 3). The presentation was concluded with an explanation of best work practices derived from the task-based, real-time analysis.
4. Results

4.1 Real-Time Exposure Assessment

The respirable dust reduction was very similar between wet suppression (80.9 percent) and local exhaust ventilation (78.6 percent) (See Table 2). The wet suppression control proved to be more effective in reducing peak exposures. The reduction in peak exposure was 70.0 percent for wet suppression and only 54.6 percent for local exhaust ventilation. Wet suppression also appears to be more consistent in reducing peak levels of dust throughout the saw process (See Appendix 1). Regardless of reductions in peak exposures, local exhaust ventilation still appears to be similar in its overall dust reduction capabilities to wet suppression.

A detailed, task-based analysis of the cutting process provided additional information regarding when the highest exposures occurred during cutting. Without dust control, both the peak concentrations and the mean concentrations appeared to be much higher during the head cuts and the walk time following the head cut (See Appendix 2). Wet suppression also displayed the highest peak and mean concentrations during either the head cut or the walk time following the head cut (See Appendix 3). LEV revealed similar results with the exception of the third flat cut (See Appendix 4). Overall, these controls were less effective during vertical cuts versus horizontal cuts (i.e. 67% less effective for LEV controls and 76% less effective for wet suppression).

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Table 1. Overview of Task-Based Analysis.

<table>
<thead>
<tr>
<th>Task</th>
<th>Task Descriptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) Start</td>
<td>Begin: Sample commencement. Worker preparation for first cut.</td>
</tr>
<tr>
<td>2) Flat Cut 1</td>
<td>Begin: Cutting commences for the first saw joint. Cut front, flat section of the curb.</td>
</tr>
<tr>
<td>3) Head Cut 1</td>
<td>Begin: Cutting commences on incline of the back, head of the curb. Cut vertical head of curb for the first saw joint.</td>
</tr>
<tr>
<td>4) Walk 1</td>
<td>Begin: Cutting is terminated for the first saw cut. Move equipment approximately 10 feet to second curb joint.</td>
</tr>
<tr>
<td>5) Flat Cut 2</td>
<td>Begin: Cutting commences for the second saw joint. Cut front, flat section of the curb.</td>
</tr>
<tr>
<td>6) Head Cut 2</td>
<td>Begin: Cutting commences on incline of the back, head of the curb. Cut vertical head of curb for the second saw joint.</td>
</tr>
<tr>
<td>7) Walk 2</td>
<td>Begin: Cutting is terminated for the second saw cut. Move equipment approximately 10 feet to third curb joint.</td>
</tr>
<tr>
<td>8) Flat Cut 3</td>
<td>Begin: Cutting commences for the third saw joint. Cut front, flat section of the curb.</td>
</tr>
<tr>
<td>9) Head Cut 3</td>
<td>Begin: Cutting commences on incline of the back, head of the curb. Cut vertical head of curb for the third saw joint.</td>
</tr>
<tr>
<td>10) Finish</td>
<td>Begin: Cutting is terminated for the third saw cut. All immediate actions following the last cut.</td>
</tr>
</tbody>
</table>

Notes: The completion point of each task is the time immediately before the commencement of the next task. The last task is defined as a fifteen second period.
Table 2. Summary Statistics for Exposure Control Methods.

<table>
<thead>
<tr>
<th>Control</th>
<th>Trial</th>
<th>T</th>
<th>AM (SD)</th>
<th>Maximum</th>
<th>Median Peak</th>
<th>µ</th>
<th>Reduction (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td>1</td>
<td>74</td>
<td>2.51 (3.71)</td>
<td>14.2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wet</td>
<td>1</td>
<td>86</td>
<td>1.76 (3.75)</td>
<td>17.4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LEV</td>
<td>1</td>
<td>84</td>
<td>3.16 (5.37)</td>
<td>26.0</td>
<td>17.4</td>
<td>2.48</td>
<td></td>
</tr>
<tr>
<td>None</td>
<td>2</td>
<td>88</td>
<td>0.38 (0.52)</td>
<td>2.09</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wet</td>
<td>2</td>
<td>99</td>
<td>0.34 (0.74)</td>
<td>5.77</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LEV</td>
<td>2</td>
<td>107</td>
<td>0.70 (1.13)</td>
<td>5.20</td>
<td>5.20</td>
<td>0.47</td>
<td>80.9</td>
</tr>
<tr>
<td>None</td>
<td>3</td>
<td>137</td>
<td>0.51 (1.07)</td>
<td>8.87</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wet</td>
<td>3</td>
<td>118</td>
<td>0.57 (1.05)</td>
<td>7.89</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LEV</td>
<td>3</td>
<td>117</td>
<td>0.51 (0.63)</td>
<td>3.00</td>
<td>7.89</td>
<td>0.53</td>
<td>78.6</td>
</tr>
</tbody>
</table>

Notes: LEV= Local Exhaust Ventilation; Wet=Wet Suppression; T=time in seconds; AM (SD)= Arithmetic Mean (Standard Deviation); µ=grand mean.

\[ \mu = \frac{\sum_{i=1}^{n} AM}{n} \] \[ \% = \left( \frac{\mu_{None} - \mu_{Control}}{\mu_{None}} \right) \times 100 \]

A visual analysis of the recorded videos revealed similar results as the quantitative measurements. For all exposure control methods, the worker was required to bend closer to the curb during the head cut. During the head cut, the dust was not ejected cleanly behind the worker, and it was deflected off the ground and towards the worker. This resulted in a visible cloud of dust around the worker during this task. As the worker turned to walk, the dust appeared to trail the worker for at least half of the distance between cuts. As a result, the worker was exposed to the deflected dust as they walked to the next cut.

4.2 Construction Supervisor Survey

The quantitative and visual results from the real-time exposure assessment were used to develop the training presentation for the supervisor survey. The appropriateness of the three videos (See Appendix 5) incorporated in the training presentation was assessed and confirmed using both the quantitative and visual results. For the 116 construction supervisors trained, 101 (87 percent) returned the voluntary survey. Fifty-one percent of participants considered themselves an onsite worker, 24 percent as an onsite supervisor, 8 percent as upper management, and 17 percent as other (e.g. safety professional). Ninety-three percent of these workers reported that they were aware that dust exposure and a variety of its components were regulated by law prior to the training. Ninety-seven percent of workers also understood that overexposure to dust was a significant health concern in construction. The participants were then asked to rank cost (operation and capital), usability (ease of use), productivity (operational efficiency), and safety (employee acceptance, exposure reduction, additional PPE requirements) in order of importance when selecting a tool. Only 66 percent of participants believed safety was the most important.
When asked whether the addition of the exposure graphic below the video changed their perception of dust levels during this operation, seventy-five percent of participants answered “yes”. Eighty-five percent of participants also answered “yes” when asked if they would investigate changing current uncontrolled work practices after watching the third side-by-side video. Finally, 90 percent of participants would consider using a video-based training library to train workers for other work processes. When asked what would utilize free safety training materials, approximately 31 percent preferred professional organization endorsements, 29 percent preferred placement on a government website, 27 percent preferred the first return on a search engine, and 13 percent replied with other methods.

5. Discussion

The quantitative real-time concentration values clearly correlated with the visible dust in the videos. In the side-by-side rendered videos, participants were able to visualize a very evident dust reduction for both wet suppression and local exhaust ventilation when compared to no control. In addition, the participants were also able to visualize the cutting process and the requirements of each control. Seventy-five percent of workers did feel that the rendered video impacted their perception of exposure magnitude, and approximately 85 percent would investigate changes to this process after watching the side-by-side video. Perhaps, most importantly, participants exhibited interest in using similar videos of other processes to train workers.

In collaboration with NIOSH’s workplace solutions database, the Center for Construction Research and Training (CPWR) currently provides a comprehensive database of solutions to control hazards for specific tasks in construction (The Center for Construction Research and Training (CPWR), 2009). The database is searchable by construction task, listing hazardous exposures, risks, and practical control measures for each process. Currently, the database does not include multimedia for worker training, but could easily be adapted to include exposure monitoring videos. Inclusion of these videos would be helpful for the contractor during equipment acquisitions and tool-specific training exercises.

6. Conclusions

Interestingly, this case study exhibited that construction supervisors were knowledgeable in the risks associated with silica exposure, but many still prioritize by cost, usability, and productivity above safety and exposure when selecting a tool. The case study reaffirms the importance of incorporating these factors in control design and conveying this information appropriately to contractors. An accurate perception of exposure is critical to the use and implementation of hazard controls. It is recommended that an electronic library of exposure monitoring videos be developed to provide contractors with this valuable tool-specific information. The use of these
real-time videos could also play an important role in analyzing motion and time of processes extending beyond safety and health hazards.

7. Acknowledgement

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8. References


Appendix 1. Instantaneous Respirable Dust Exposure for Sampling Periods.

<table>
<thead>
<tr>
<th>Trial</th>
<th>No Control</th>
<th>Wet Suppression</th>
<th>Local Exhaust Ventilation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td><img src="#" alt="Graph" /></td>
<td><img src="#" alt="Graph" /></td>
<td><img src="#" alt="Graph" /></td>
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<tr>
<td>2</td>
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<td>3</td>
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</table>

Notes: See Table 1. for detailed task descriptions.

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Appendix 5. Supervisor Training Videos.

1. Video 1: Video of cutting process without dust control.

2. Video 2: Rendered video of cutting process without dust control.

3. Video 3: Side-by-side rendered video of all three dust control options.

Notes: Video 1: Video of cutting process without dust control. Video 2: Rendered video of cutting process without dust control. Video 3: Side-by-side rendered video of all three dust control options.