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Construction Ergonomics: Concrete Bit Wear Increases Handle Vibration and Drilling Time

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The use of large electric hammer and pneumatic drills exposes construction workers to high levels of hand vibration that may lead to hand arm vibration syndrome and other musculoskeletal disorders. This hammer drill test bench study demonstrated a small but significant increase in z-axis handle vibration (4.8 to 5.1 m/s^2; ISO weighted) and drilling time per hole (7.8 to 12.3 s) with worn concrete bits when compared to a new bit. Drill bit manufactures may consider advising contractors that worn bits will increase the exposure of workers to hand vibration and will reduce worker productivity. Construction contractors should adopt a bit replacement program based on bit wear patterns in order to reduce exposure level and drilling time to hazardous hand vibration.

INTRODUCTION

Electric hammer drills are widely used in commercial construction for drilling into concrete for structural upgrades and anchor bolt placement. Pneumatic rock drills, the primary tool used for dowel and rod work, have been gradually replaced by new, more powerful electric hammer drills. Although electric hammer drills may expose workers to less hand-vibration and noise compared to pneumatic drills, the exposure to these hazards still remains high (Phillips et al. 2007). Hand vibration exposure may lead to hand-arm vibration syndrome, damage to the blood vessels, nerves, bones, joints, muscles or connective tissues of the hand and forearm (Palmer et al. 2001; Bovenzi 2005).

The average handle vibration levels of electric hammer drills (Nataletti et al. 2008) are higher than the threshold limit value recommended by the ACGIH (2017) and the European Community Directive (2002). Typical handle vibration levels for hammer or rock drills vary from 6 to 20 m/s^2 (Griffin et al. 2006). Accurate exposure data is essential because the relationship between vibration level and the threshold limit value maximum exposure time is exponential.

While studies have investigated the relationship of bit sharpness (e.g., wear) to cutting productivity, the relationship between bit wear and drill handle vibration has not been evaluated.

The purpose of this study was to use an automated test bench system to evaluate the effect of concrete bit wear on hammer drill handle vibration and productivity (e.g., bit penetration rate). This approach improves reliability and reduces variability of measures compared to measurements collected while experienced workers perform drilling. The null hypothesis was that bit sharpness does not change handle vibration levels or productivity. There were no human subjects.

METHODS

This laboratory study was conducted using a new test bench system for hammer drills that has been previously described and validated (Rempel et al. 2017). Details of this study can be found elsewhere (Antonucci et al. 2017). Briefly, a hammer drill (Hilti TE-70) is secured to a 6-axis load cell by a force adjustable grip placed at the drill handle location where a hand would hold the drill. Linear actuators automatically and repeatedly position the drill and drive the active drill into a concrete block under closed-loop feed force control (i.e., weight-on-bit force). The measured outcomes during drilling are productivity (e.g., drilling time per hole) and handle vibration. The system follows the design recommendations of the EU, ISO, and German BG BAU IFA guidelines for a test bench system (EN 1093-3:2006; CEN: CMT4-CT97-2166; BG BAU 617.0-FF 421 2006).

Non-reinforced concrete blocks (10 x 15.25 x 58.4 cm) were prepared on site according to EN and ISO standards (slump 80 mm; EN 206-1:2000; ISO 679; ISO 28927-10) and cured for at least 28 days.

Tool handle vibration acceleration magnitude was measured and interpreted according to ISO 28927 (2011). Drill handle vibration was measured with a tri-axial piezoelectric accelerometer (Larson Davis

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SEN040F; sensitivity of 1mv/g) attached to the drill handle at the location of handgrip using a hose clamp and oriented according to ISO 5349-2 (2001) (z-axis aligned with drill bit axis; x-axis vertical). Only one axis was measured for each hole drilled due to the limitations of the data logger (Svantek 912AE). The accelerometer was calibrated at the beginning and at the end of each test by a PCB Piezotronics 394C06 calibrator. The signals were analyzed by Svantek software (SVANPC V2.3w) to generate the 1/3 octave spectra as well as the unweighted (a_h) and weighted (a_{hw}) acceleration levels for each axis and total value according to ISO 5349-1 (2001).

Four levels of bit wear were produced by manually, repeatedly drilling holes of 19 cm in depth into concrete block. The four levels correspond to cumulative drilling depths (CDD) of 0, 1900, 5700, and 7600 cm (Figure 1). All bits were 34.3 cm long, 1.9 cm in diameter, 2-cutter carbide. The drill and bits used in the study are typical of the tools used in the trades.

Handle vibration and drilling rate experimental data were collected for each of the 4 bit wear levels on the test bench during the drilling of 18 holes; 6 holes for each axis of acceleration measurement. Hole depth during the experiment was 7.5 cm and the target feed force was 150 N. Productivity was estimated for each cumulative drilling depth level by averaging the drilling time per hole over the 18 holes drilled. Differences in acceleration and productivity were evaluated statistically using one-way ANOVA with Tukey follow-up test to correct for multiple comparisons.

RESULTS

Drilling productivity (e.g., drilling time per hole) was significantly influenced by bit wear ($p=0.00001$) (Table 1). The reduction in productivity was relatively linear from a new bit to the bit with 5700 cm cumulative drilling depth wear.

There was little effect of bit wear on unweighted x-axis, y-axis, and combined (total) acceleration (a_h) levels (Table 1). However, the unweighted z-axis acceleration level was significantly lower for the new bit than any of the worn bits based on the overall ANOVA ($p=0.00001$) and Tukey follow-up tests. A similar pattern was observed for weighted acceleration (a_{hw}) with significant effects only along the z-axis ($p=0.003$).

DISCUSSION

This novel laboratory study used a test bench system to systematically evaluate the effects of bit wear on hammer drill handle vibration. To some extent, both frequency weighted (a_{hw}) and unweighted (a_h) handle vibration levels were influenced by bit sharpness. The effects were significant only in the z-axis; the axis collinear to the forearm. The unweighted z-axis vibration level increased 11.3%, from 42.7 m/s^2 with a new bit to 47.5 m/s^2 with a 1900 cm cumulative drilling depth bit. The increase in z-axis vibration level was less evident for weighted acceleration, which heavily discounts the high frequencies.

Z-axis handle vibration is proportional to the energy reflected back from the drill bit impacting concrete. The percussive system of the hammer drill tested operates at a frequency of 46 Hz so that the tip penetrates the concrete under compressive stress leading to tensile cracks and the formation of pulverized concrete. After each strike, the bit tip rotates slightly splitting the concrete and the bit blades move to a new strike area. Some of the energy from the impactor is imparted to crush concrete and some of the energy is reflected back to the tool handle. As the bit becomes dull, less energy from each impact is transferred to splitting the concrete and instead is reflected back up the bit.

Other laboratories have developed automated laboratory drilling platforms for investigating bit characteristics and penetration rates but they have not evaluated tool handle vibration levels (Abtahi et al. 2011).

Another important factor to consider when estimating exposure to drill handle vibration is that the drilling time per hole is longer with a worn bit compared to a new bit. A moderately worn bit (1900 cm CDD) increases drilling time by 32% while a very worn bit (5700 cm CDD) increases drilling time by 58%. For the bit tested wear progressed up to somewhere between 1900 and 5700 cm of cumulative drilling depth bit wear. Beyond that point there was little further effective wear.

Bit wear will affect the number of holes a worker can drill per day due to the time spent drilling if the exposure is near the threshold limit value (ACGIH, 2017). At a handle vibration level of 8 m/s^2 a_{hw} the threshold limit value is 187 minutes of vibration exposure per day. If it takes 2 minutes to drill a hole with a sharp bit, at most, a worker could drill 93 holes per day. With a very worn bit, it would take 3.2 minutes to drill the same hole, and, at most, a worker could drill 58 holes per day.

Other hazardous conditions should be considered for workers performing concrete drilling, such as exposure to noise, exposure to silica dust, and fall from height. A different study demonstrated that bit wear will increase respirable silica dust levels (Carty et al., 2017)

CONCLUSIONS

This hammer drill laboratory study demonstrated a small but significant increase in z-axis handle vibration and drilling exposure time with worn concrete bits when compared to a new bit. Drill bit manufactures may consider advising contractors that worn bits will increase the exposure of workers to hand vibration and will reduce worker productivity. Construction contractors should consider adopting a bit replacement program based on bit wear patterns (e.g., reduced bit width, change in fluke angle, tip edge rounding; Botti et al. 2017). However, additional controls, such as reduced exposure time to vibrating hand tools, may be necessary to reduce exposure to hazardous tool vibration levels.

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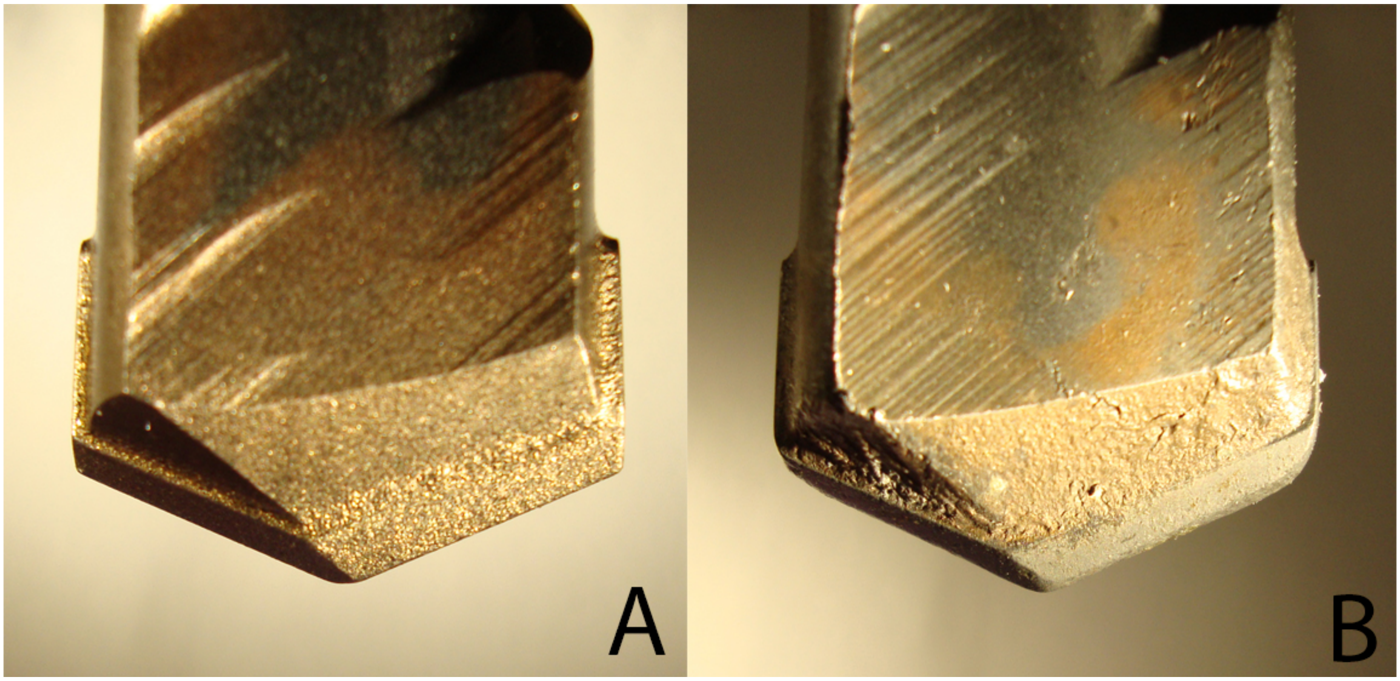

FIGURE 1. Examples of two levels of bit wear: a new bit (A) and a bit with 1900 cm of cumulative drilling depth wear (B).

TABLE 1. Mean (SD) drilling time per hole (7.5 cm depth holes) and unweighted and ISO weighted handle vibration levels by bit wear level in cumulative depth drilled.

	Bit Wear (cumulative drilled depth)				
	0 cm	**1900 cm**	**5700 cm**	**7600 cm**	**P-value**
Drilling time (s)	7.8 (0.4)^{abc}	10.3 (0.7)^{ade}	12.3 (0.6)^{bd}	11.8 (0.7)^{ce}	0.00001
Unweighted (a_h)					
X-Axis (m/s^2)	67.7 (2.4)	65.2 (4.9)	68.4 (3.8)^{a}	61.6 (2.8)^{a}	0.03
Y-Axis (m/s^2)	45.4 (2.3)	47.3 (1.1)	44.1 (1.7)	45.5 (2.0)	0.10
Z-Axis (m/s^2)	42.7 (1.3)^{abc}	47.6 (1.6)^{ad}	45.6 (0.7)^{b}	45.1 (0.6)^{cd}	0.00001
Total (m/s^2)	92.1 (2.1)	93.6 (3.3)	93.3 (3.5)	88.9 (2.6)	0.07
Weighted (a_{hw})					
X-Axis (m/s^2)	5.5 (0.2)	5.4 (0.3)	5.7 (0.3)	5.3 (0.1)	0.08
Y-Axis (m/s^2)	2.7 (0.2)	2.9 (0.2)	2.6 (0.1)	2.8 (0.1)	0.05
Z-Axis (m/s^2)	4.8 (0.1)^{abc}	5.1 (0.1)^{a}	5.0 (0.1)^{b}	5.0 (0.2)^{c}	0.003
Total (m/s^2)	7.8 (0.2)	8.0 (0.3)	8.0 (0.2)	7.8 (0.1)	0.14

Note: Same superscript in a row indicates significantly different vales by the Tukey test.