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Granite polishing: Effects of polishing parameters and tool paths on part quality and dust emission

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Abstract

Machining is necessary to shape parts but it is also an important source of pollution (such as dust and aerosols) and this constitutes hazards for machine-tools operators. The emission of dust depends on machining conditions, processes, tooling, and machining strategies. The shop floor air quality is thus of great concern when shaping dusty materials such as granite as this process generates harmful dusts. In recent times, the occupational health and safety regulations have become more severe. On the 24th of March 2016, the US department of Labor's, occupational Safety and Health Administration (OSHA) announced the reduction of the exposure limit for inhalable crystalline silica dust by half. To quickly comply with these new regulations, engineers and researchers must help industries in developing strategies to limit workers risk of exposure to the silica. This paper investigates the emission of fine and ultrafine particle emission when polishing granite as a function of machining conditions and parameters. The main goal is to determine machining conditions leading to less dust emission while maintaining acceptable part quality and productivity.

Keywords: Granite; Polishing; Part quality, Fine and ultrafine particle emission

1. Introduction

The main purpose of hard stones polishing is to improve the part surface quality, form and dimensional accuracies. For this task, different combinations of abrasives, spindle and travel speeds and tool path are used. The machining of hard stones, due to the crystalline silica (SiO_2) that it generates, is being pointed out as a source of occupational diseases such as: silicosis, lung cancer and other respiratory diseases [1-5]. As a consequence, in March 2016, the United States of America reduced the maximum exposure limit for respirable silica dust by more than half of it current value [2]. It is now 50 $\mu g/m^3$ for an eight hour working shift. This revision was also the result of the following [6]: (i) more evidence that old exposure limits did not adequately protect workers; and ii) evidence that exposures to SiO_2 below 100$\mu g/m^3$ caused silicosis and cancers. The emission and size distribution of dust generated during granite polishing depends on machining operation, parameters, materials and abrasive tools used [7]. It is thus critical to found solutions for limiting workers exposure to these harmful particles. The use of water in minimum quantity lubrication (MQL) mode was found to be effective in reducing fine particles in the air during semi-wet polishing of granite, but not ultrafine particles [8].

The purpose of the current article is to study the part quality, and the fine and ultrafine particles emission during polishing of granite materials, in relation to the machining conditions, abrasive tools grits sizes and tool path used. The work is intended to provide information for limiting the dust emission at the source while improving the part quality and the productivity.

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2. Experimental procedure

The polishing was conducted in a closed CNC milling machine (28,000 rpm capacity), allowing the dust sampling to be carried out in a closed environment. Polluted air in the machine was sucked into the particle measurement system through a 10 mm diameter polyester tube (back tube in Fig. 1b). The tube, about 305 mm long, is kept up straight to minimize sucked particles. The polishing tool (Fig. 1a and c) was a 50.8 mm diameter diamond abrasives tool mounted on a rigid tool holder. The polishing conditions are listed in Table 1. Fine particle (FP) emissions were measured using an APS (Aerosol Particle Sizer,) capable of sampling particle size ranging from 0.5 to 20 µm. Ultrafine particle (UFP) emissions were measured using an SMPS (Scanning Mobility Particle Sizer), equipped with a nano DMA (Differential Mobility Analyzer), Fig. 1d. This system can measure particle size ranging from 7 to 300 nm. The workpiece materials used were two granites: black (12% Si) and white (52% Si), [9].

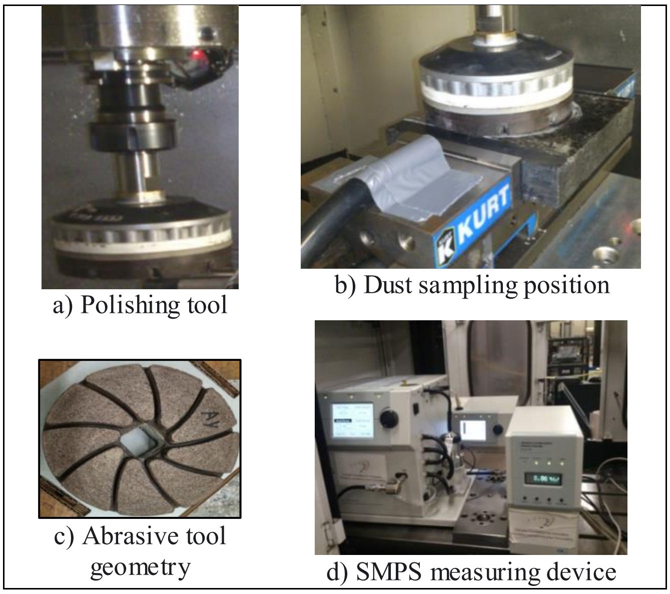

Fig. 1: Experimental setup & equipment.

Table 1: Polishing conditions

Abrasives grit sizes	45-1800
Feed rates: V_t (mm/min)	254-2032
Spindle speed: Vs (rpm)	250 - 2000
Polishing tool diameter	50.8 mm (2.0 in)
dust sampling distance	1.9 mm (0.75 in)

3. Results and Discussions

3.1 Chips and particle morphology and Si content

Fig. 3 presents the analysis of the percentage of silicon in black and white granites during dry polishing. It revealed that the dust collected during the polishing of white granite contains more silicon than the one collected when polishing the black granite. This result can be explained by the fact that the white granite contains 40% more silicon than the black granite [9]. This high amount of silicon in white granite dust can be also explained by the presence of quartz within white granite (quartz 41%) compared to black granite which contains no quartz, [8]. Fig. 2 presents the SEM morphology images of the particles obtained when polishing black and white granites at different speeds. The effect of the polishing speeds tested on particles shapes was not significant; however, particles are more agglomerated with an increase in the polishing speed for black granite as compared to white granite. This observation could be due to their mechanical property difference, as well as to the fact that white granite contains more abrasive Si particles than black granite.

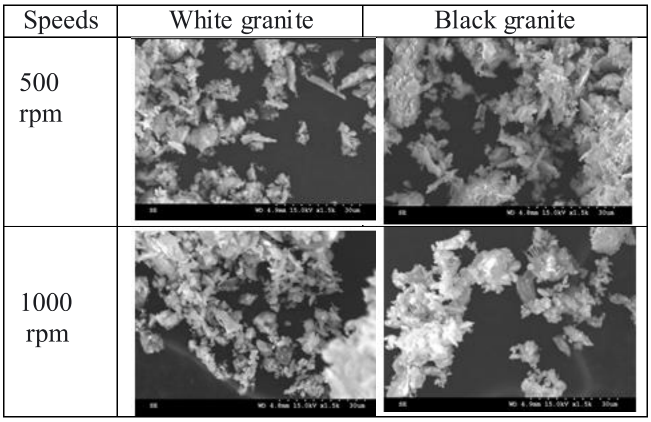

Fig. 2: SEM images of particles obtained during polishing (Feed rate: 508 mm/min; tool grit size: 60; pressure:0.2 bar)

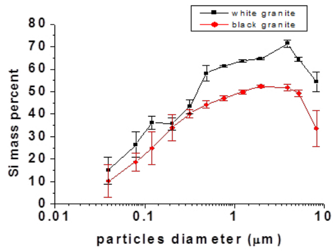

Fig. 3: SEM analysis of Si-content of granite dust as a function of the particle size: (1000 rpm; Grit size: 45); [8].

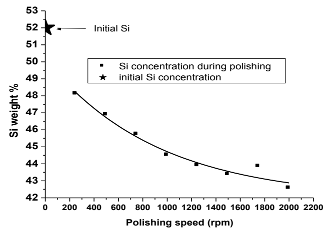

Fig. 4: Variation of Si-content of particle obtained at different polishing speeds (white granite; Vt:8.4 mm/s; Abrasive grid size: 60)

For a given polishing process combining rotation and translation of the polishing tool, the particle morphology did not vary with the polishing speed (Fig. 2). However, the composition of the emitted dust and especially its Si-content varied with the dust particle size (Fig. 3) and the cutting speed used (Fig. 4). Using high polishing speeds thus lowers the concentration of Si within the dust, but the total number of dust particle emitted might increase (Fig. 11). The effect of feed rate on Si-content was similar to that of the speed.

3.2 Effects of feed rate, spindle speed and abrasive grit sizes on Part surface finish

Figs 5-7 display the evolution of the Ra-values and Rt-values as a function of abrasive grit sizes (Fig. 5), polishing speed (Fig. 6) and feed rate (Fig. 7). Higher speeds, higher feed rates and higher abrasive grit sizes all led to better surface finishes. The use of the high speeds and feed rates also means that higher productivity is achieved.

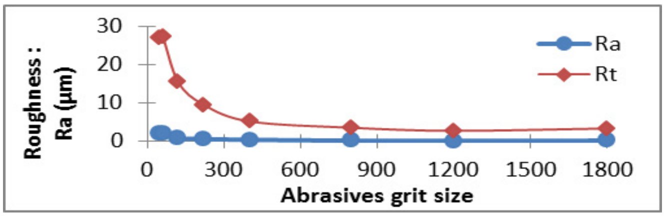

Fig. 5: Evolution of Ra and Rt as a function of the abrasive grit size (Vs: 1000 rpm; Vt: 508 mm/min)

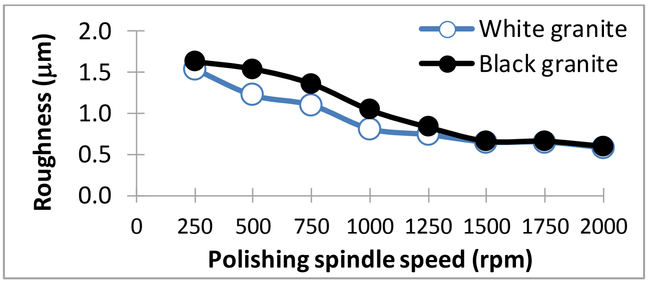

Fig. 6: Ra-values as a function of polishing speed (Vt: 508 mm/min; Abrasive grit 60)

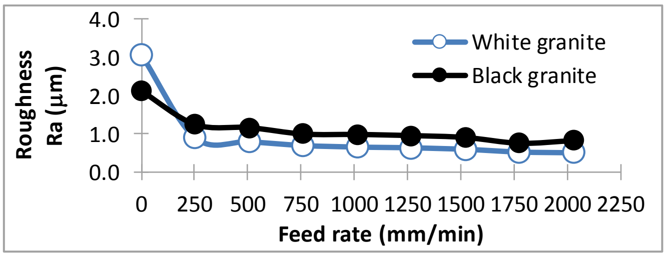

Fig. 7: Ra-values as a function of the feed rate (Vs: 1000 rpm; Abrasive grit 60)

3.3 Effects of feed rate, spindle speeed and abrasive grit sizes on Fine particles (FP) emission

The number concentration of the particle emitted increased with the abrasive grit sizes during roughing operations and was quite constant in finishing operations using large grit sizes (Fig. 8). This is in good agreement with observations made by Saidi et al. [7] who observed that during roughing operations, the chip formation by brittle fracture leads to a high amount of fine particle.

Higher feed rates leads to the emission of lower quantity of fine and ultrafine particles (Figs. 9-10) while the use of higher spindle speeds led to the high emission of dust (fine and ultrafine) particles, Fig. 11. Since the abrasive tools are made of multiple individual grits randomly distributed on the tool surface, with each experiencing a different cutting speed, thus the use of higher feed rates should be recommended.

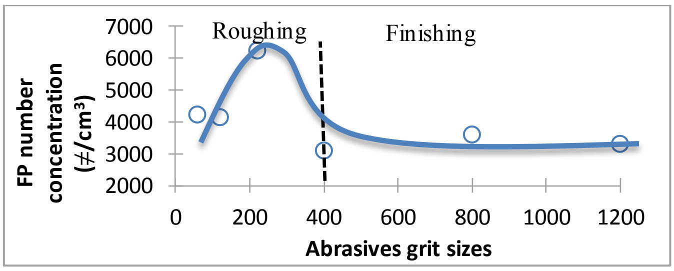

Fig. 8. Fine particle emission when polishing **black granite** as a function of the abrasive grit size (Vs: 1000 rpm; Vt: 508 mm/min)

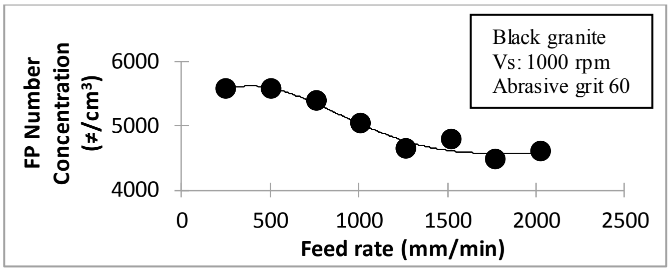

Fig. 9: Particle emission when polishing **black granite** as a function of the feed rate (Vs: 1000 rpm; Abrasive grit size: 60)

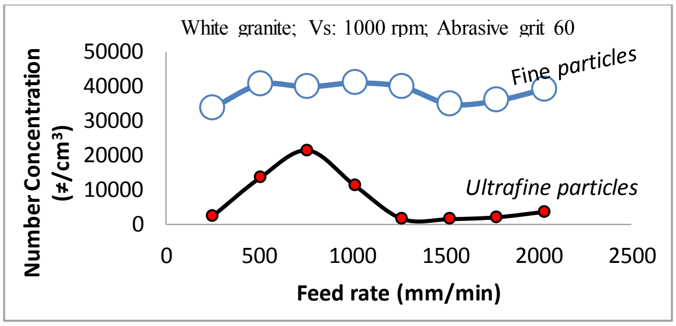

Fig. 10: Effect feed rate on Fine and ultrafine particle number concentrations

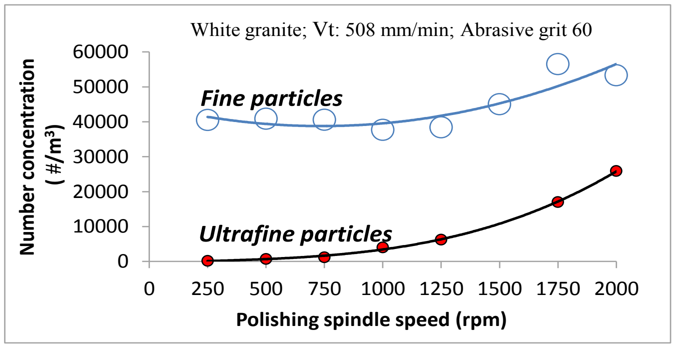

Fig. 11 Effects of polishing speed on fine and ultrafine particle number concentrations

3.4 Effects of tool path on Fine particles (FP) emission

Three tool paths were tested: linear and arcs (Fig. 12) and a spiral tool path starting at the center of the workpiece. The tool path tests were conducted under the following conditions: workpiece: white granite; abrasives: Grit80; Vs : 1000 rpm; Vt: 508 mm/min.

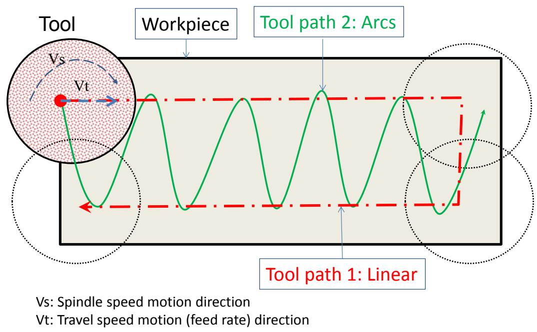

Fig. 12: Schematic representation of linear and Arc tool paths

The linear tool path generated surface finish with higher Ra-value (Fig. 13) and high amount of fine particle emission as compared to the arc and spiral tool paths (Figs 14 and 16).

This can be explained by number of abrasives passing at a given spot. The spiral tool path generated more ultrafine particles (results of fine chip load and crushing action on particles trapped between the tool and the workpiece) than other tool paths (Fig. 15) but low fine particle (Fig.14).

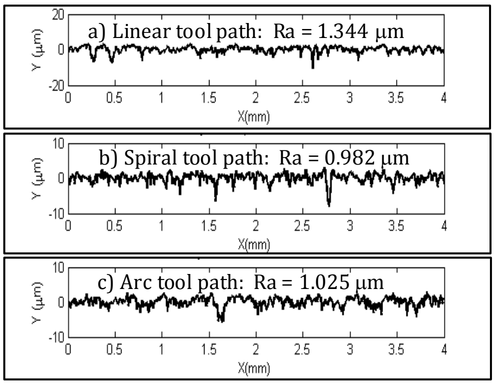

Fig. 13: Effects of tool paths on surface roughness profiles

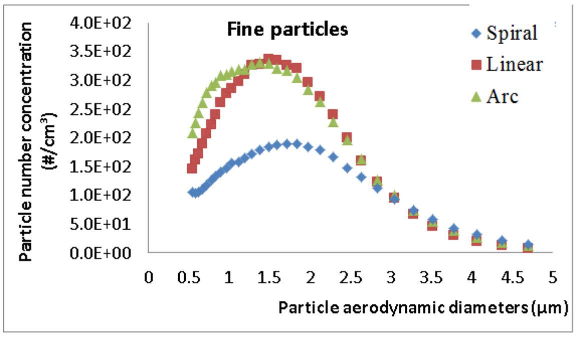

Fig. 14: Effects of tool paths on **fine particle** emission and distribution

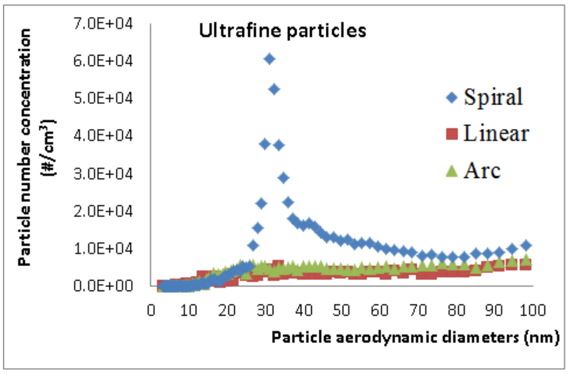

Fig. 15: Effects of tool paths on **ultrafine particle** emission and distribution

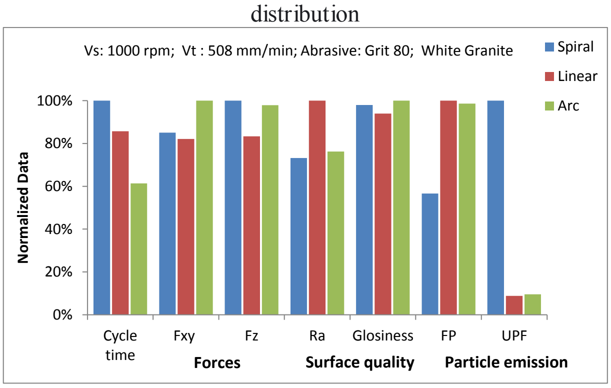

Fig. 16: Comparative effects of tool path on cycle time, cutting forces, part surface quality and on particle emission.

Conclusions

This work was aimed at studying the effects of the polishing conditions (abrasives grit sizes, polishing speed, feed rate and tool path strategy) on part quality and on dust emission. The following concluding remarks can be drawn:

- Polishing conditions (feed rate, spindle speed) and tool path strategy can be used to reduce the dust emission to some extent while maintaining the part quality and the productivity at acceptable levels. Higher feed rates and higher polishing speeds led to better surface finishes.
- In general, the tested tool paths did not change the particle size distributions; fine particles (0.5-4.5 µm) and ultrafine particles (3-100 nm) were both detected.
- The spiral tool path improved the part surface finish and reduced the fine dust emission but did increase the emission of ultrafine particles; The reduction of particle emission was about 43% to 90% depending on the type of particle considered, but the residual number of particle were still high (about 200 ppc for fine particles and 5000-6000 ppc for ultrafine particles). Polishing conditions optimisation should be conducted and alternative methods for removing these particles from the machine-tools should be investigated.

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