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Effect of tool lead angle and chip formation mode on dust emission in dry cutting

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Abstract

Dry machining and high speed machining are increasingly attempted because of their impact on manufacturing cost. However, these processes generate dust that can be harmful. Environmental regulations require that manufacturers reduce manufacturing hazards, hence the need to develop environmentally conscious processes and cutting strategies that will help them to achieve that goal.

This work investigates the turning of the 6061-T6 aluminium alloy, and 1018 and 4140 steels, using carbide cutting tools. The cutting tool geometry and the cutting speed are varied and their effect on dust formation and chip formation studied. The size of the dust particle investigated is 2.5 μm and under (PM2.5). A new dust unit, which can be used as an ecological factor, is introduced to compare the dust emissivity of the tested materials. This dust unit is then related to the cutting conditions, and experimental models are developed. A correlation is established between the chip formation, the tool lead angle, the cutting speed, and the dust emission, in order to determine the conditions required for minimal dust emission.

Keywords: Dry turning; Dust formation; PM2.5; Tool geometry

1. Introduction

Clean machining is becoming one of the important issues at stake in future manufacturing. This technology has become attractive because of the serious problems associated with traditional machining: health and environmental issues and wear of the elements of the machine-tool. Most of these problems are caused by metallic particles generated during cutting and by cutting fluids (splash, evaporation and bacterial contamination) [1].

To decrease the negative environmental impact of the cutting fluid, lubricants were improved either by introducing biodegradable fluids or by reducing the quantity of the biodegradable fluid used [2]. In spite of that reduction, the remaining biodegradable fluids can also be a highly subject to bacterial contamination, which is the most severe and difficult to correct type of contamination. The complete removal of the lubricant in order to protect operators' health and the industrial environment while minimizing recycling and machining costs was also proposed [3,4]. These propositions have led to new machining techniques such as dry machining [4–12] and semi-dry machining [3,13], also called *nearly dry machining or minimal quantity of lubricant* (MQL) *machining* [3,14–19].

In studying clean machining, most authors focus on the cutting fluid [4,6,12,20–22], and insufficient attention has generally been devoted to dust emission topic [23–27,34–36]. It was shown by Tönshoff et al. [35] that during grinding, most of the metallic dust generated is breathable (dangerous for worker health), and that without a dust suction system, the level of dust particle concentration in the air is higher than the threshold fixed set US regulations [35]. In their study of the release of aerosols during the sawing and milling of beryllium metal and alloys, Hoover et al. [36] found that brittle materials (such as beryllium metals) produce larger size dust (diameter greater than 25 μm) than ductile materials (Be-copper and Be-nickel alloys).

Airborne particles from machining remain suspended in the environment long enough to be inhaled by workers [34]. This dust can be very harmful, especially when the size of the particles generated is too small, as this leads to the following situations (i) particle reactivity is inversely proportional to the size (instantaneous oxidation); (ii) removal and filtration difficulties [28,29]. Exposure to metallic dust causes mild to serious

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diseases [21,32,33], and so the conditions under which fine particles are generated must be determined in order to limit their production. Few authors have studied dust emission as a function of the manufacturing processes. Zipf and Bieniawski [27] proposed a model of fine dust emission during the machining of coal, but without a mathematical formalism or an interpretation of the dust emission phenomenon. Works by Balout et al. [25,26,30] showed that during machining, ductile materials produce more dust than do brittle materials. These authors [25,26,30] found a correlation between chip formation and dust formation. The formation of a discontinuous chip being accompanied by a weak emission of dust as compared to the dust obtained when a long chip is formed. However, it is known that the type of chip formed during machining depends not only on machined materials, but also on tool geometry and on cutting conditions.

We intend to extend their work to cover the turning process. In the present work, we study the influences of tool geometry, materials and cutting conditions on the generation of fine dust particles (PM 2.5). To achieve this, turning tests were carried out on aluminium and steel materials using tools of various lead angles and at various cutting speeds. The influence of these conditions and of the materials on dust emission and chip formation were studied.

2. Experimental procedures

2.1. Dust sampling system and cutting conditions

Air quality control in the industrial environment is usually carried out in free air by sampling particulate matter smaller than 2.5 μm (PM 2.5) or by gas receptors, in situations where the main polluters are gases. An evaluation of the process emissivity must be done using high sensitivity methods. Carrying out measurements in free air (far from the cutting zone) is the usual method for air quality control. But that is not appropriate for determining the emissivity of operations and the emissivity of materials. Free air measurement involves large sampling volumes, and thus considerably increases the testing time and reduces dust concentration. In the laboratory, when studying dust emissions in relation to the cutting process, materials and cutting conditions, the following points should be taken into account:

Table 1
Conditions and parameters used during the test

Operation	Turning
Feed rate (mm/rev)	0.1
Depth of cut (mm)	0.5
Cutting speed (m/min)	0–300
Tool material	Uncoated carbide
Lead angle (°)	70–110
Lubricant & coolant	None
Work piece materials	Aluminium alloy 6061-T6 AISI 1018 & AISI 4140 steels

i. The detached particles propagate in the environment in a stochastic manner (Brownian motion, atmospheric composition, turbulence caused by machine-tool motion and ventilation),
ii. The particles do not easily diffuse in the air, and they are not uniformly distributed due to the stochastic motion of the air.
iii. There are various sources of emission in machining (different zones of emission with quantity depending on process type and stability).

To know the emission capacity of each operation therefore, the system must be isolated in order to ensure that the measurements are for the dust produced by the operation under study. A system was designed to allow the insulation of the machining process while the particles produced during machining are sampled (Fig. 1). A laser photometer (TSI8520 Dustrack) was used to measure the dust produced. This device is connected to the dust recovery enclosure by a suction pipe (1.7 l/min flow) which passes through a filter allowing only particles with an aerodynamic diameter lower than 2.5 μm to go through the measuring device. A computer equipped with a data acquisition and analysis system is also connected to the measuring device.

The cutting conditions used for the experiments are summarized in Table 1.

2.2. Procedure for evaluating the processes and cleanliness of materials

Fig. 2 shows a typical dust emission curve during a cutting operation. It presents the dust particle concentration in the air versus the acquisition time. The measuring device evaluates the concentration at each second interval. The settling time (the time required for the particles produced to go through the measuring device) is very long compared to the cutting time, which is only a couple of seconds.

The total dust quantity (surface under the curve of Fig. 2) seen by the measuring device depends on the metal removal rate, the work piece material type

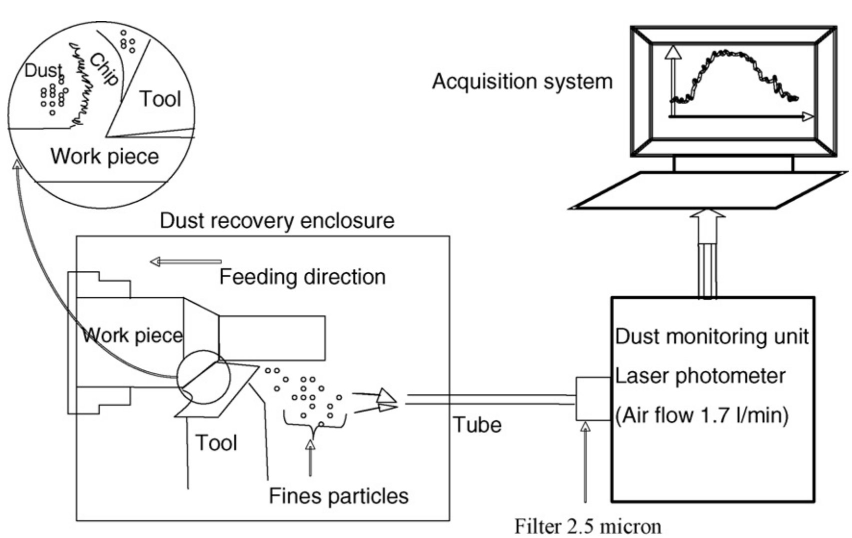

Fig. 1. Experimental setup.