CIRP Annals - Manufacturing Technology 57 (2008) 363–366

Contents lists available at ScienceDirect

CIRP Annals - Manufacturing Technology

journal homepage: http://ees.elsevier.com/cirp/default.asp

Optimisation of fluid application in grinding

M.N. Morgan [a,*], A.R. Jackson [a], H. Wu [a], V. Baines-Jones [b], A. Batako [a], W.B. Rowe (1)[a]

[a] AMTReL, Liverpool John Moores University, Byrom Street, Liverpool, UK
[b] Cinetic, Landis Grinding Ltd., Keighley, West Yorkshire, UK

ARTICLE INFO

Keywords:
Grinding
Coolant
Fluid delivery

ABSTRACT

This paper addresses the quantity of fluid required for grinding and the method of application. Results from this research suggest that supply flowrate needs to be 4 times the achievable 'useful' flowrate. Extra flowrate is wasted. It is shown that jet velocity and jet flowrate can be separately specified. Improved system design allows 'actual' useful flowrate to approach 'achievable' useful flowrate. Achievable useful flowrate depends on wheel porosity and wheel speed whereas actual useful flowrate depends on nozzle position, design, flowrate and velocity. Experimental methods are complemented by computational fluid dynamics (CFD) simulations.

1. Introduction

Waste occurs because supply flow fails to become useful flow that reaches inside the grinding contact. Only useful flow can lubricate the grinding action, prevent wheel wear and clogging, maintain low surface roughness and prevent excessive grinding temperatures. At very high wheel speeds, fluid delivery requirements increase machine costs and power demands [1]. Information from the UK government suggests that purchase, management and disposal of metal working fluids can in some cases approach 15% of manufacturing costs [2]. There is also an environmental impact of grinding fluid.

Various researchers found that useful flow rate depends on nozzle position, jet speed and wheel porosity [3–5]. Engineer et al. [5] found that percent useful flowrate was 5–20% of jet flow. Akiyama et al. [6] found 20–40%. Chang et al. [7] analysed depth of fluid penetration into a porous wheel and predicted smaller depth at higher wheel speeds. Gviniashvili et al. [8] found that useful flowrate was maximised with the nozzle as close as possible to the contact zone. Ebbrell et al. [9] demonstrated deflection of the grinding fluid by the air boundary layer at high wheel speeds, also the benefit of using an air scraper in front of a nozzle. A nozzle tangential to the wheel and positioned 10–25° before the contact zone was seen as optimal for jet delivery [10–12]. If jet speed equals wheel speed, a tangentially directed jet can easily displace air because the liquid momentum is greater than the air momentum. However, at lower jet speed the jet may be required to point more directly towards the wheel to avoid being deflected. Optimum angle may therefore depend on jet speed/wheel speed ratio. Webster et al. [13] showed the need for jet coherency. The present paper aims to find practical ways to estimate fluid delivery requirements.

* Corresponding author.

0007-8506/$ – see front matter © 2008 CIRP.
doi:10.1016/j.cirp.2008.03.090

2. Useful flow programme

A flow separator was developed, Fig. 1, allowing useful flow to be collected over a timed period while actually grinding. The system captures fluid passing through the contact region but excludes other flow. Sensors monitored temperature, acoustic emission, power and force [14].

The capacity of the wheels to transport fluid through the grinding contact was determined by measuring the surface topography of the wheels.

Wheel porosity after dressing and also after wear was investigated. Replication techniques were employed and evaluated by optical scanning systems. A typical image obtained from optical interferometry is shown in Fig. 2, with porosity shown in blue. Achievable useful flowrate was estimated based on surface porosity.

Achievable useful flowrate was estimated from:

$$Q_u = f h_{pores} b v_s \phi \qquad (1)$$

where h_{pores} is mean pore depth roughly equal to mean grain size, v_s is wheel speed, Φ the porosity is typically 0.5 for a medium porosity wheel and f is a factor based on measurement and is approximately equal to 0.5. It was found that actual useful flowrate is usually less than flowrate required to fill the surface pores (Fig. 3).

Useful flowrate varies linearly with wheel speed (Fig. 3) up to a speed exceeding jet speed. The linear portion under the best conditions represents achievable useful flowrate over the speed range. Further increase in useful flowrate requires a more porous wheel. Increased jet velocity in the linear region serves only to increase energy consumption.

Fig. 4 shows that excessive jet supply flowrate fails to increase useful flowrate. Excessive supply flowrate reduces percent useful flow and increases rejected flow while useful flowrate is only marginally increased. Increasing jet velocity increases useful flowrate slightly until wheel speed is reached. After this there is

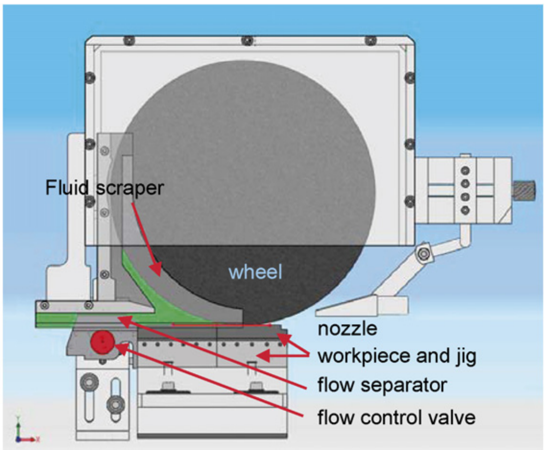

Fig. 1. Useful flow separator.

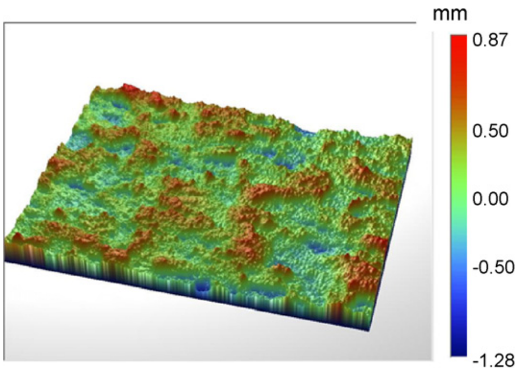

Fig. 2. Optical image of a wheel surface.

reduced benefit. For the medium porosity wheel shown, maximum useful flowrate was typically 25–30%. However, for the high porosity Alumina wheel, maximum useful flowrate could be increased to a maximum of 50%. These figures allow jet flowrate to be specified in terms of achievable useful flowrate. A suggested guideline is that

$$q_{jet} = 2bh_{pores}v_s \quad (2)$$

where b is the grinding width.

From the topography tests and comparison with maximum measured useful flowrates, it was found that it was possible to achieve approximately 60–70% pore space filling with the very porous Alumina wheel. With the medium porosity WA60KVL wheel it was only possible to fill 50–60% of the pore space under the best conditions. These results suggest that a 50% assumption is a reasonable basis for estimating achievable useful flowrate.

Taguchi experiments evaluated useful flowrate with variations in wheel speed, work speed, dressing depth, material, nozzle position, jet velocity and nozzle flowrate. Tests were conducted for medium porosity wheels, high-porosity wheels and wheels with large aspect ratio grains.

It was shown that wheel speed, jet velocity and nozzle flowrate were of greatest importance for actual useful flowrate. It was confirmed that jet speed should be approximately 80–100% of wheel speed to match achievable useful flowrate. The jet speed should not be higher as this does not significantly increase useful flowrate.

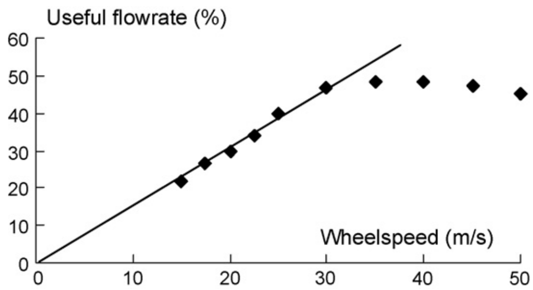

Fig. 3. Useful flow (%) and prediction. Flow = 18.9 l/min, $v_{jet} = 24.2$ m/s. Alumina wheel 54% porous.

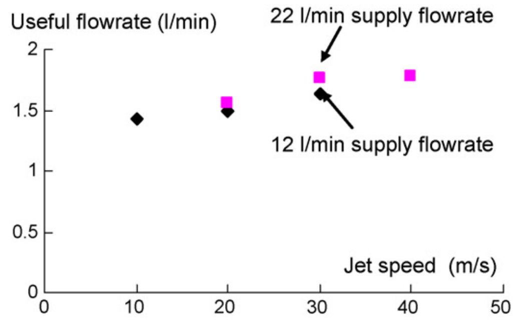

Fig. 4. Useful flowrate vs. jet speed for two different flowrates where $v_s = 30$ m/s, $a = 30$ μm, $v_w = 10$ mm/s, wheel WA60KVL 44% porous.

3. Nozzle experiments and CFD analysis

Scraper effects obtained from CFD simulations of a rotating rough wheel (Fig. 5) show that a scraper should immediately precede nozzle position since the boundary layer quickly re-develops (low pressure shown in blue) [15]. Effect of nozzle shape on jet coherence was also investigated.

The effect of nozzle position on useful flowrate was measured experimentally. The results in Fig. 6 are for a convex nozzle based on the design by Rouse et al. [16] where the optimum distance was 5 cm. It can be seen that useful flowrate reduces with increasing nozzle distance from the grinding contact.

Multi-phase simulations were developed in ANSYS CFX and validated with experimental measurements using the Pitot tube method [15]. An experimental fluid jet velocity profile is shown in Fig. 7. Jet width increases as jet length increases and mean jet velocity falls. Jet velocity falls away further from the centreline and the area of peak velocity reduces with distance from nozzle orifice.

Coherent length C_L, was defined as the distance at which the area of peak jet velocity diminishes to zero. This definition implies that it is better to position the jet at a distance significantly less than the coherent length since at a distance equal to the coherent length, peak velocity would not cover any of the width of the wheel. Predicting coherence length allows nozzle position to be determined such that the area of peak velocity is at least equal to the area of the grinding width [15].

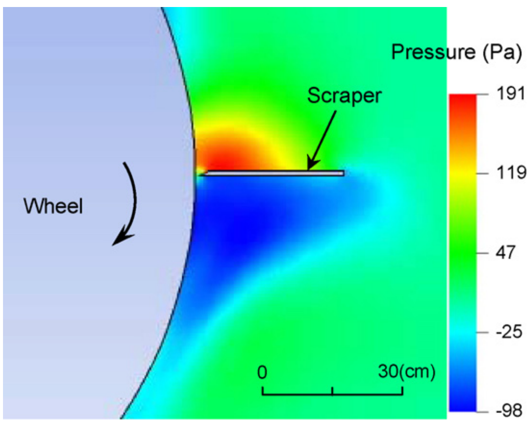

Fig. 5. Simulation result of air pressure distribution around scraper with clockwise wheel rotation.