Development of a new cutting fluid delivery system for creepfeed grinding

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Abstract: This paper develops and validates a new cutting fluid application technique for creepfeed grinding with aluminium oxide grinding wheels. The new fluid delivery system incorporates several concepts found in the literature including high-speed fluid application, coherent jets, air scrapers and concentration effects associated with synthetic cutting fluids. Experiments were carried out on a Blohm Planomat 408 creepfeed grinding machine in Dalhousie University's Grinding Laboratory. These experiments show that the new coolant delivery system can achieve an 83% increase in material removal rate over a state-of-the-art coherent jet and provide the capability of keeping the liquid cutting streams separate during creepfeed grinding. As a result, this new system has the potential to significantly increase production rates.

Keywords: creepfeed grinding; high-speed cutting fluid delivery; cutting fluid concentration; cubic boron nitride; grinding wheels; cutting fluids; aluminium oxide.

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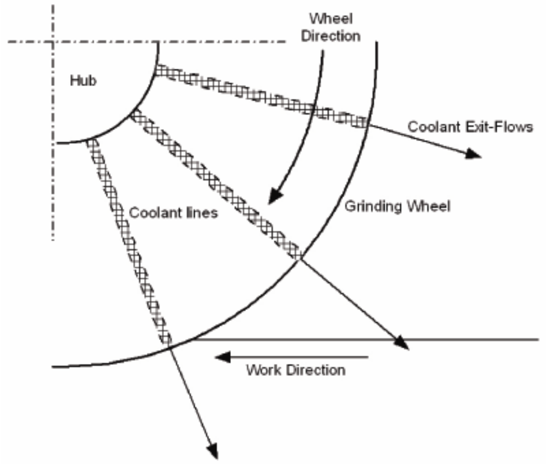
1 Introduction

There has been significant research interest in developing improved coolant delivery systems for the creepfeed grinding process in order to achieve higher Material Removal Rates (MRR) and improved economic benefits. Some of the more promising research in coolant delivery systems presented in the literature include radial jets, floating nozzles, solid lubricants, grooved wheels, useful fluid application, coherent jets, high-speed delivery, air scrapers, cutting fluid concentration effects and dual cutting fluid. This research is briefly described in the following subsections. A new fluid delivery system that incorporates several of these concepts is then described in Section 2, experimental results are discussed in Section 3 and conclusions are drawn and recommendations are made in Section 4.

1.1 Radial jets

Various researchers have advanced the concept of delivering the cutting fluid from the centre of a grinding wheel to its periphery by channelling the fluid through the wheel itself instead of more conventional delivery systems which direct fluid at the grinding zone via a nozzle (Xu et al., 2001; Zitt and Schäfer, 1998). A schematic of this radial jet coolant delivery technique can be seen in Figure 1.

Figure 1 Radial jet schematic

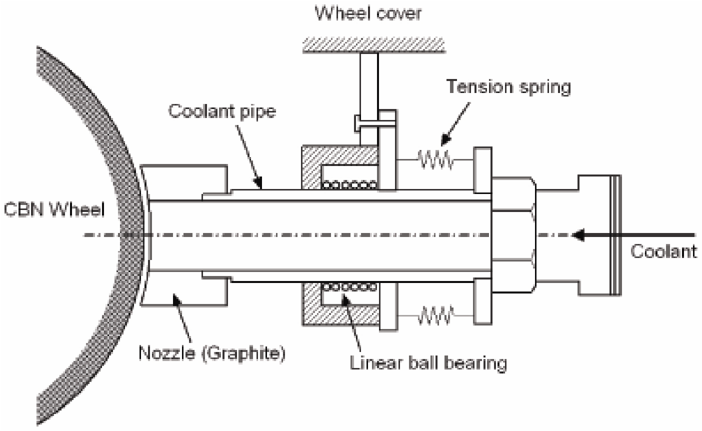


Xu et al. (2001) carried out research with this radial cooling technique. Although the construction of the wheels and coolant delivery system is more complex than conventional coolant application, Xu et al. were able to increase the critical heat flux, improve the cooling effectiveness in the contact zone, and increase overall efficiency of the grinding process. With radial jets the temperature of the workpiece surface in the grinding zone was consistently kept below the film boiling temperature of 100°C–120°C for water-based coolants.

1.2 Floating nozzles

This coolant delivery system consists of a nozzle with an exit facing the grinding wheel, a delivery tube and a spring mechanism to ensure contact with the wheel. Graphite is used on the front of the nozzle so that it can be easily ground by the wheel as shown by the system schematic in Figure 2.

Figure 2 Floating nozzle



Source: Ninomiya et al. (2004).

Ninomiya et al. (2004) found that a floating nozzle on a CBN wheel can reduce wheel wear by 50% for shallow depths of cut and low workpiece speeds. It was also found that the surface finish was enhanced under these conditions and, when compared with traditional coolant application, this system used one twelfth of the cutting fluid. Unfortunately, it was discovered that when the work speeds were increased beyond 20 m/min there was significant wheel wear.

1.3 Solid lubricants

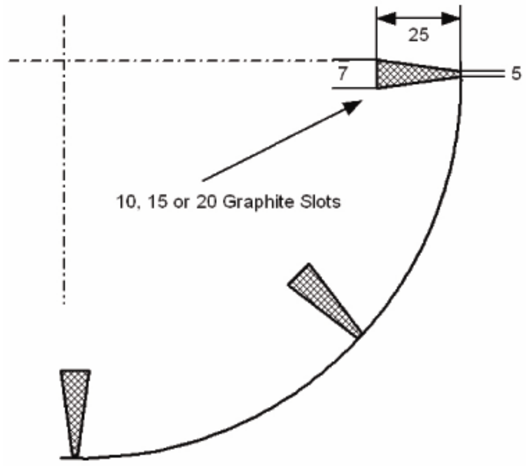
Graphite is often used as a solid lubricant because of its weakly-bonded hexagonal plate structure (Callister, 1999). Recently Molybdenum disulfide (MoS_2) has been used by Salmon (2003) as a 'hard lubricant' and Titanium Aluminium Nitride (TiAlN) has been used to resist wear on CBN wheels. This new coating does not need to run in oil (which is typical for CBN wheels), but performs adequately in water-based fluids. The researcher believes that these coated wheels have the potential to surpass traditional wheels and have the advantage of operating with the more environmentally friendly water-based coolants.

Shaji and Radhakrishnan (2001) compared the performance of graphite paste grinding with dry grinding and conventional wet grinding. The graphite paste was a

1:1 ratio of powder graphite to water-soluble oil. The study revealed lower tangential forces, grinding zone temperatures and specific energies with the graphite paste when compared to dry grinding or conventional wet grinding. The graphite assisted grinding also showed a lower ratio of tangential to normal force suggesting less friction.

Shaji and Radhakrishnan (2003) have also studied graphite impregnated in slots which were machined on the grinding wheel. As shown in Figure 3, wheels with varying numbers of graphite slots (10, 15 and 20) were used in the study. The graphite wheels improved the surface roughness, residual stresses and hardness profiles of the workpieces for small depths of cut.

Figure 3 Graphite slots



1.4 Grooved wheels

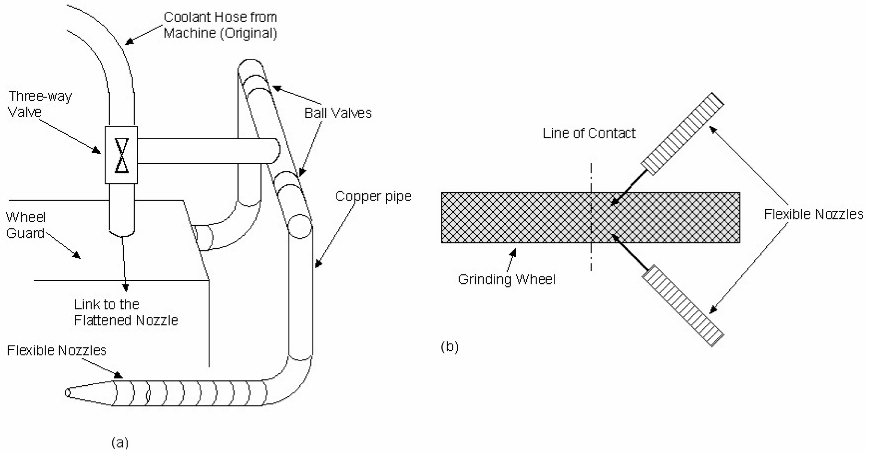
Okuyama et al. (1993) were able to increase the heat transfer coefficient to the coolant by having 4–36 small grooves, 3 mm wide and 0.5 mm deep, machined on the periphery of the grinding wheel. Increasing the heat transfer coefficient can lead to more efficient grinding where less energy is transferred to the workpiece resulting in less thermal damage. According to Okuyama et al. (1993) grooves in the grinding wheel are able to elevate the heat transfer coefficient because coolant is held by the grooves and stirred as it passes through the grinding zone. As the number of grooves increases, it was found that there was a corresponding increase in the heat transfer coefficient. The researchers suggest that the grooves have the possibility of improving the efficiency in heavy grinding with superabrasive wheels with no porosity.

1.5 Useful fluid application

The term 'useful flowrate' describes how much cutting fluid is transported through the grinding zone. It is generally accepted that the more fluid you can pass through the grinding zone, the greater the MRR will be. Useful fluid application occurs when the coolant delivery system is optimised so that all of the fluid being applied is used to effectively lubricate and cool the grinding zone or provide bulk cooling of the workpiece.

Zhong and Yee (2001) used flexible nozzles to deliver coolant to the sides of the wheel and workpiece, effectively bulk cooling the workpiece. With this set-up, it was found that there was a significant improvement in surface finish and it appeared that the closer the nozzles were to the workpiece, the better the cooling performance (see Figure 4 for a schematic of the set-up).

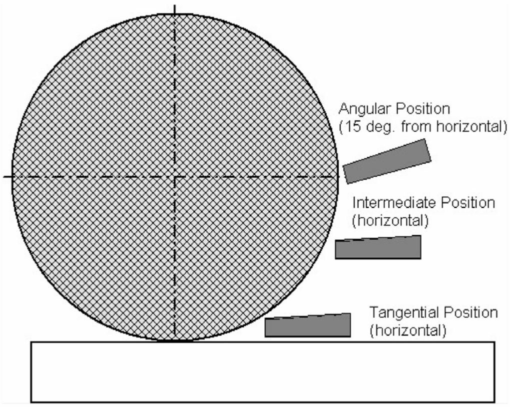
Figure 4 Side Zhong set-up (a) overall view and (b) top view



Source: Zhong and Yee (2001).

Ebbrell et al. (2000) investigate the position for a free jet to try to maximise the amount of fluid going through the grinding zone. Using three nozzle positions, as shown in Figure 5, the useful flow rate was collected and compared. Ebbrell et al. determined that, for their set-up, the most effective position for a free jet was the intermediate position.

Figure 5 Free jet nozzle positions



Source: Ebbrell et al. (2000).

Inoue and Aoyama (2004) used cold air at −33°C with a flow rate of 320 l/min at a pressure of 0.2 MPa for bulk cooling. This set-up was an attempt to use the least amount of fluid possible during grinding (Minimal Quantity Lubricant, or MLQ). The lubricant in these experiments was 'salad oil' supplied at 6 ml/min. The results from this set-up were compared with dry grinding and grinding with an oil-based fluid supplied at 0.4 MPa and 50 l/min. In general, the study showed that when using air and oil for shallow depths of cut, the temperatures, surface roughness and post-grinding surface hardness can be comparable to that of more traditional cutting fluid application.

1.6 Coherent jets

One of the more popular upgrades to creepfeed grinding processes is the use of a coherent jet. A coherent jet is characterised by a stream of fluid that does not disperse with distance from the nozzle exit. When compared to a conventional free-jet coolant delivery system, Steffen et al. (2005) were able to increase the MRR by over 60% using a coherent jet. A schematic of a coherent jet can be seen in Figure 6. The guidelines for coherent jet nozzle design and application are summarised as follows (Webster, 1999):

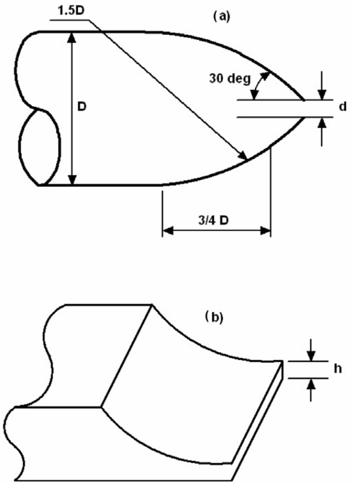
- Nozzle surface finish should be smooth and concave.
- Nozzle should have sharp exit edges.
- Nozzle should have a high contraction ratio from inlet to exit.
- Elbows and changes in the plumbing diameter should be avoided; a straight pipe placed between a flow conditioner and nozzle is needed to encourage a uniform-velocity flow condition.
- There may be no need for profiled nozzles since a large single round coherent nozzle or several smaller round coherent jets can be utilised. If expensive rectangular nozzles must be used, an aspect ratio of 5–8 is recommended.
- There should be low-pressure fluid flow on the back edge of the workpiece to prevent burn.
- The lower the Reynolds number the more coherent the jet.
- With high porosity wheels, water-based fluids can have higher removal rates when compared to straight oils; however, for dense wheels the opposite appears to be true. Bo-Yi (1998) has also confirmed this last point for creep-feed grinding of metal with a shoe nozzle.

An interesting feature about coherent jet nozzles is that their angular position relative to the wheel does not greatly affect the MRR Steffen (2004). Furthermore, since the jet is coherent, the fluid can be easily aimed at specific locations.

1.7 High-speed delivery

Kovacevic and Mohan (1995) studied high-speed jets and compared the results to traditional flooding techniques. Their jets produced an exit velocity of 365 m/s and a relatively low flow rate of 3.64 lpm for grinding. Kovacevic and Mohan found that there was an overall improvement in the grinding results when comparing forces, acoustic emissions and surface finish when creepfeed grinding with aluminium oxide wheels.

Figure 6 Coherent jets (a) round nozzle and (b) traditional nozzle



Source: Webster (1999).

1.8 Air scrapers

Ninomiya et al. (2004), Ramesh et al. (2001), Campbell (1995) and Okuyama et al. (1993) have all used scraper plates to try and increase the cooling efficiency. It is suggested by the authors that a scraper plate disrupts the air boundary layer around the grinding wheel and allows more fluid to come into contact with the wheel and workpiece. Campbell (1995) has shown that the critical grinding wheel speed could be increased by 22% with the use of an air scraper. In this study, the critical grinding wheel speed was defined as the maximum rpm for a given size of wheel where coolant flow is still present in the grinding zone. This result suggests that one may be able to increase the MRR of a system by adding a scraper plate.

1.9 Cutting fluid concentration effects

Yoon and Krueger (1999) found that the concentration of the cutting fluid can affect the G-ratio of the process. The G-ratio is defined as:

$$\text{G-ratio} = \frac{\text{Volume material removed}}{\text{Volume of wheel consumed}} \tag{1}$$

This study showed that a normally diluted synthetic cutting fluid had a G-ratio of 2.5–7.5; however, an undiluted cutting fluid could achieve a G-ratio of 120. It is widely accepted that as one increases the lubrication in a machining process two phenomena are typically observed:

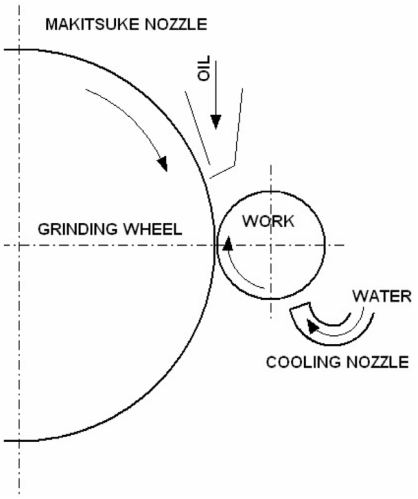
- tool wear decreases
- surface finish improves.

By increasing the concentration of a synthetic fluid one is increasing the lubrication properties of the fluid. However, this increase in lubrication is often at the expense of a decrease in cooling properties of the fluid.

1.10 Dual cutting fluid

Yokogawa and Yokogawa (1993) developed a cutting fluid system for cylindrical grinding that uses oil to lubricate the grinding zone and water to cool the workpiece during heavy grinding operations (Figure 7). The different specific gravities between water and oil were used to separate the liquids after grinding. The results of this study showed an improvement in surface roughness and it was suggested that the grinding zone temperatures can dramatically decrease with this technique.

Figure 7 Dual cutting fluid application



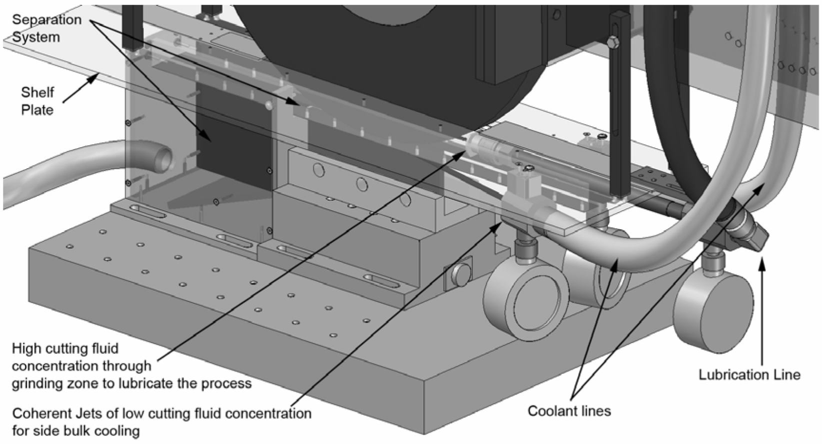
Source: Yokogawa and Yokogawa (1993).

2 Development of a new cutting fluid application system

This paper introduces a new cutting fluid application technique for creepfeed grinding that combines the dual fluid concept of Yokogawa and Yokogawa (1993) with the minimal quantity lubricant approach of Inoue and Aoyama (2004). The lubrication is delivered via a high-speed free jet similar to that used by Kovacevic and Mohan (1995) and positioned in accordance with the research findings of Ebbrell et al. (2000). Instead of using two different cutting fluids, the proposed technique uses only one fluid – in two different concentrations, as supported by the research of Yoon and Krueger (1999) who showed that as one increases the concentration of a synthetic cutting fluid the lubrication properties increase. The workpiece is cooled via a redesigned coherent jet similar to that used by Steffen et al. (2005) and air scrapers are also used to try and increase the MRR and to help keep the fluid separate at all times as discussed by Hryniewicz et al. (2000).

The proposed system is shown in Figure 8 where a high concentration synthetic cutting fluid is passed through the grinding zone to lubricate the system, while a low concentration is delivered to the sides of the workpiece via coherent jets to remove the heat generated and prevent corrosion. The two flows are kept separate using baffles and air scrapers. The proposed system allows the flows to remain separate even after they pass over the workpiece.

Figure 8 Proposed coolant delivery system



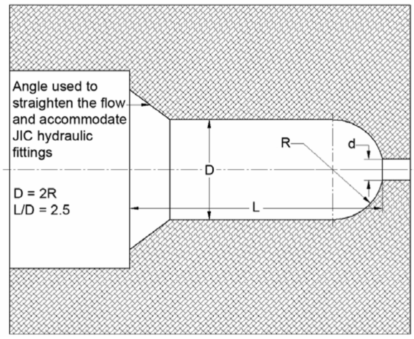
The new system was installed on a Blohm Planomat 408 grinding machine, equipped with a Load Controls Incorporated PH-3A Power Cell spindle power sensor and a Kistler 9257B force dynamometer, in order to study the resulting wheel wear, maximum depth of cut and material removal rate. The cutting fluid used in the research is CIMTECH® 310 Synthetic Metalworking Fluid manufactured and distributed by CIMCOOL Global Industrial Fluids and Milacron Canada Inc. As shown in Figure 8, the new system is made up of three parts: a bulk coolant system, a lubrication system and a separation system.

2.1 Bulk coolant system

The side coherent jet nozzles supply a low concentration of cutting fluid for bulk cooling of the workpiece. This fluid is maintained at a concentration high enough to prevent corrosion of the workpiece, machine tool and associated fixtures.

Figure 9 shows a schematic of the coherent jet nozzle design used to achieve the side bulk cooling. This coherent jet nozzle design is based on the coherent jet nozzle design used by Steffen et al. (2005) and exhibits the following features: concave inner walls, sharp exit edge, smooth inner surfaces, round exit aperture and high contraction ratio (ratio of nozzle inlet to exit diameter).

Figure 9 New coherent jet nozzle

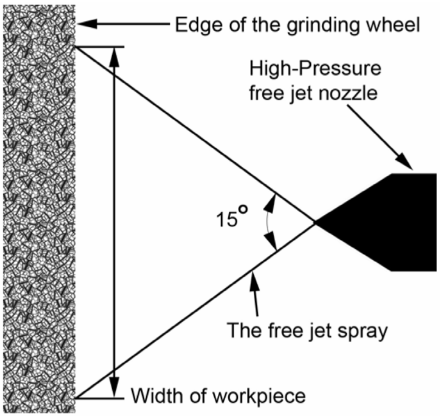


The side coolant nozzles are offset so that the coolant stream can be aimed precisely at the side of the work piece where it is needed. The 2 mm exit aperture operates at a pressure of 700 kPa and the flow rates can be varied between 0 and 9.5 lpm. After the fluid washes over the workpiece, it is collected and filtered through a large Cyclotron reservoir.

2.2 Lubrication system

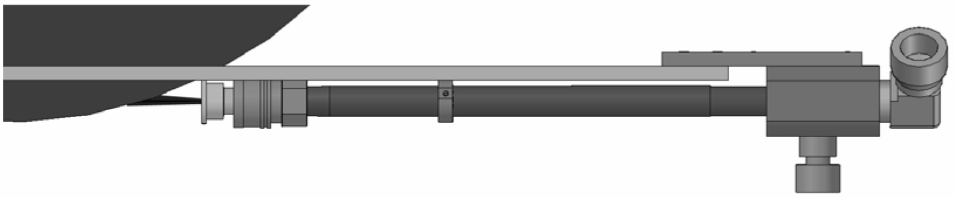
To lubricate the grinding zone a High-Pressure (HP) free-jet nozzle design was implemented as shown in Figure 10. The free-jet nozzle was positioned so that the width of the spray on contact with the grinding wheel was equal to the workpiece width of 6.4 mm. A free jet has been shown to be able to pass up to 82.5% of the cutting fluid through the grinding zone when aimed at the wheel in a direction parallel to the top edge of the workpiece (Ebbrell et al., 2000). As a result, the lubrication line used in the proposed system can follow along the bottom of a shelf plate (parallel to the top edge of the workpiece) as shown in Figure 8 and there is no need for a complex nozzle positioning system.

Figure 10 Spray diagram, top view



Using the HP system (Figure 11) to lubricant the grinding zone, fluid exits the 1mm nozzle orifice at approximately 136 m/s with a flow rate of 6.4 lpm (the maximum flow rate of the two-stage pump system employed). This exit speed is over 6 times the 22 m/s periphery speed of wheel. While there is some literature indicating that one should match the speed of the stream to the periphery wheel speed, the work of Kovacevic and Mohan (1995) suggests a trend that the faster the fluid speed, the better.

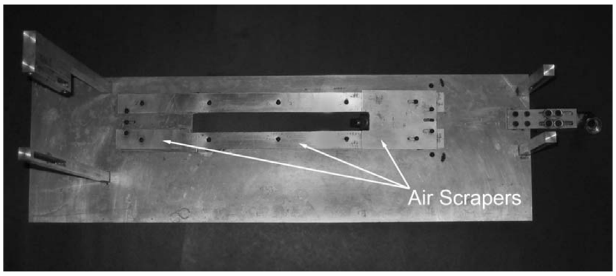
Figure 11 HP nozzle, side view



2.3 Separation system

The separation system consists of a shelf plate, air scrapers and baffle assembly. The shelf plate, shown in Figure 12, supports the two-side coherent jet coolant nozzles, the HP and high-speed lubrication free jet nozzle, as well as the air scrapers.

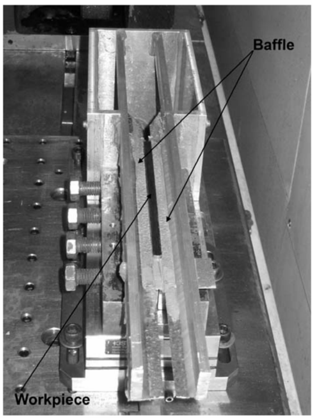
Figure 12 Shelf plate



Hryniewicz et al. (2000) showed that, when grinding with scrapers, the useful flow rate increases linearly with wheel speed. Since it is desirable to pass the maximum amount of lubrication through the grinding zone, scrapers constructed out of sheet aluminium are implemented in the proposed design. Furthermore, to minimise any cross contamination between the two concentrations of coolant being used in this research, air and fluid scrapers are located on all four edges of the wheel opening.

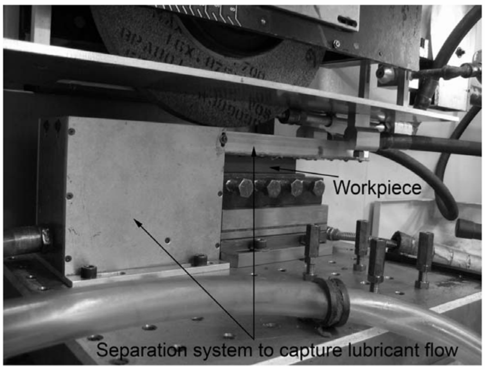
The baffle assembly consists of sheets of aluminium half a millimetre thick. As shown in Figure 13, the aluminium sheets are held in place by two 2.5 × 30 × 0.6 cm aluminium bars on either side of the sample. The sheets butt up against the workpiece just below the finished workpiece size thereby preventing cutting fluid from touching the sides the workpiece during grinding. This assembly also minimises the contamination of the high concentration stream from the low concentration coolant line.

Figure 13 Front view of separation and baffle



After the two different cutting fluid concentrations pass though their respective nozzles, there is very little mixing of the fluids. The coolant cutting fluid (low concentration) washes over the workpiece and removes heat through convection and then drains below the work table to a large coolant reservoir. The lubrication cutting fluid (high concentration) passes through the grinding zone and is contained in a small aluminium box which can be seen in Figure 14. Gravity causes the lubricating fluid to pass through a hose, which is fed under the grinding machine's worktable. The cutting fluid then empties out over a splash-way, which deposits the fluid into a stock reservoir.

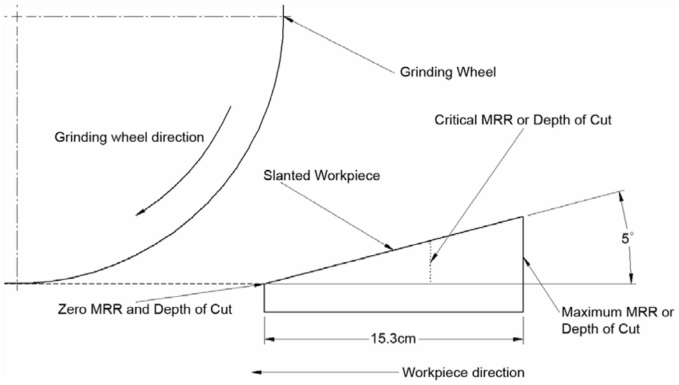
Figure 14 Installed left side view



3 Experimental results

Benchmarking experiments were first carried out to determine how the new nozzles performed. 4140A steel was ground with seven different nozzle configurations: dry, only HP lubrication and only side coherent jet cooling with apertures of 2.0 mm, 2.5 mm, 3.0 mm, 3.5 mm and 4 mm. For all of these tests, the fluid concentration was held constant at approximately 5% which is within the coolant manufacture's recommended limits for industry. During these tests, a slanted workpiece was used to enable the depth of cut to continuously vary during a single grinding pass. Figure 15 shows a schematic of the grinding geometry and a similar arrangement was used by Webster et al. (2002) in their study. With this set-up, one can minimise the amount of testing needed to determine the maximum material removal rates since a single experiment will grind at a varying depth of cut until failure occurs.

Figure 15 Slanted grinding geometry



For this grinding geometry, the dominant, failure that occurred was workpiece burn (except for the coherent jet where accelerated wheel wear was observed). In Figure 16, one can see a burned sample. When burn occurs in grinding a power spike is typically observed. This spike in power is thought to occur because, during a grinding pass, the temperature in the grinding zone increases. When the temperature is approximately 130°C, the cutting fluid in the grinding zone can experience film boiling (Webster et al., 2002). When film boiling occurs, a vapour barrier exits, which reduces the heat transfer from the workpiece to the coolant. This vapour barrier can also cause a sharp rise in the friction forces between the wheel and the workpiece thus leading to a local rise in the workpiece temperature. This temperature rise can reach to upwards of 1000°C causing the workpiece material to visually burn. The increased friction causes the forces and power to dramatically increase. The higher forces fracture the outer grains on the grinding wheel and exposing new, shaper grains. With these sharper grains, the wheel is able to cut the material again thus causing the forces and power to drop again. The vapour barrier in the grinding zone dissipates and new cutting fluid washes over the workpiece and essentially quenches it since the surface may have reached over 1000°C. This quenching can result in detrimental internal stresses caused by the change in workpiece microstructure.

Figure 16 Burn sample

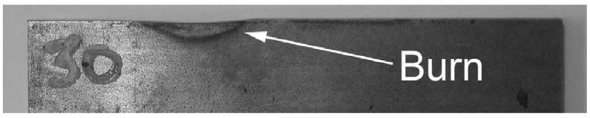
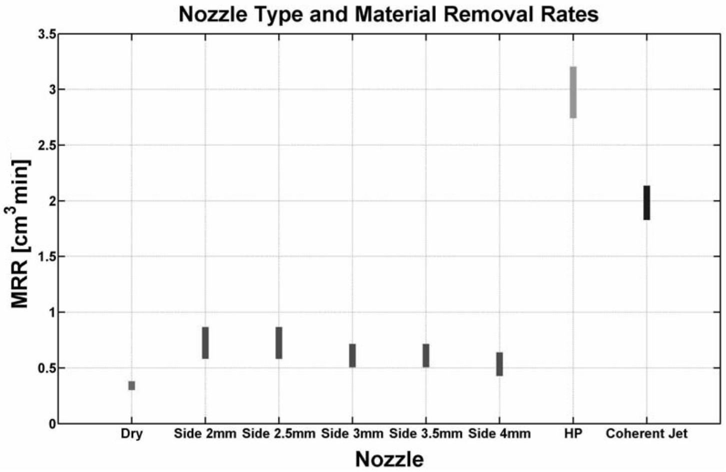


Table 1 describes the equipment and grinding parameters used in the nozzle testing. As expected, dry grinding burned almost immediately so the maximum depth of cut must be well under 0.25 mm. The side coherent jet tests showed an improvement over dry grinding, suggesting that bulk cooling of the workpiece does influence the maximum MRR. This influence is because of the added heat transfer between the fluid and workpiece not found in dry grinding. However, the results shown in Figure 17 suggest that it does not matter how much fluid strikes the workpiece from the side since all five coherent jets had comparable material removal rates.

Table 1 System parameters

Parameter	*Value*
Workpiece material and size	4140A, 15.3 × 5.1 × 0.64 cm
Feed rate	203 mm/min
Aluminium oxide wheel	RPA801F850
Wheel speed	22 m/s
HP flowrate and exit pressure	6.5 lpm@4250 kPa
2.0 mm side coherent jet flowrate and exit pressure	9.5 lpm@700 kPa
2.5 mm side coherent jet flowrate and exit pressure	20.9 lpm@700 kPa
3.0 mm side coherent jet flowrate and exit pressure	22.3 lpm@700 kPa
3.5 mm side coherent jet flowrate and exit pressure	23.3 lpm@650 kPa
4.0 mm side coherent jet flowrate and exit pressure	36.3 lpm@625 kPa
Dry	no cutting fluid

Figure 17 Nozzle results



From these results, the 2.0 mm exit orifice was implemented in the new coolant delivery system since it was the easiest to aim and used the least amount of fluid. This 2.0 mm nozzle had a jet coherency (JC) of 0.73 where jet coherency is defined as:

$$\text{JC} = \frac{\text{Diameter of stream at nozzle exit}}{\text{Diameter of stream 160 mm from exit}} \tag{2}$$

Note that 160 mm is used in Equation 2 because it represents the distance between the nozzle exit and the workpiece during the experiments.

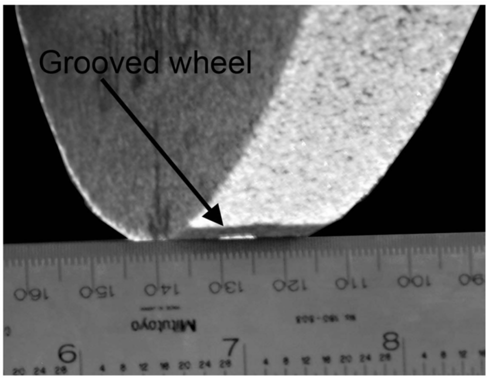
As shown in Figure 17, using the HP nozzle alone yielded a maximum MRR of approximately 2.9 cm^3/min before burn occurred, which is already an improvement over the 2.0 cm^3/min achieved with the coherent jet delivery system used by Steffen (2004).

Table 2 describes the equipment and grinding parameters used during the testing of the new coolant delivery system. Surface plunge creepfeed grinding was performed on flat workpieces during the course of this study and the maximum depth of cut was assessed. With this system, wheel failure was observed to be the threshold limit during the experiments rather than workpiece burn. In Figure 18, one can see the groove worn in the grinding wheel due to wheel wear that rapidly occurred when the maximum depth of cut was exceeded. This wheel failure phenomenon was repeatable for all of the tests when the full system was operating.

Table 2 System parameters

Parameter	*Value*
Workpiece material and size	4140A, 15.3 × 5.1 × 0.64 cm
Feed rate	203 mm/min
Aluminium oxide wheel	RPA801F850
Wheel speed	22 m/s
Lubrication flowrate and exit pressure	6.4 lpm@4250 kPa
Side coolant flowrate and exit pressure	9.5 lpm@700 kPa
Benchmark coherent jet flowrate and exit pressure	45.4 lpm@750 kPa

Figure 18 Grooved wheel

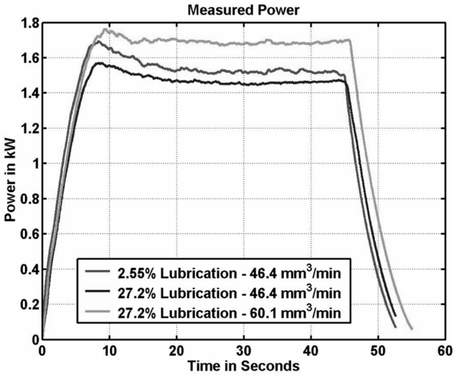


The coolant concentration for the lubrication stream was varied as follows: 2.5%, 9.3%, 17% and 27%, while the coolant stream concentration was held between 2.5% and 3.5%. The coherent jet experiments were used as a baseline for comparison with the new delivery system. The concentration level for these coherent jet experiments was 5%.

It was also found that the grinding machine required less energy to rotate the grinding wheel at the required 22 m/s when the HP nozzle was operating. Before the HP nozzle was turned on, the machine required approximately 0.15 kW to rotate the grinding wheel. When the HP nozzle was activated, the power dropped by over 70% to 0.05 kW. The reason for this power reduction is because the HP fluid stream is striking the wheel at 136 m/s and, since it is not aimed normal to the axis of rotation, there is a component of the fluid flow that accelerates the wheel thus reducing the required power to operate the machine.

The lubrication effects due to different coolant concentrations became obvious when looking at the two extremes of the testing range (2.5% and 27%) as shown in Figure 19. The maximum material removal rate for the 2.5% concentration tests was 2.79 cm^3/min with an average power of 1.45 kW when the wheel was fully engaged. When the highest concentration was used, the power dropped by over 10% for the same material removal rate. This decrease in power implies a higher grinding efficiency which translates into less energy being transferred to the workpiece and thus, less thermal damage.

Figure 19 High and low comparison in power



The other important point is that the maximum material removal rate for the highest concentration was 3.61 cm^3/min. This increase in the material removal is likely due to the increase in the lubrication between the wheel and workpiece where the cutting fluid is lubricating the grains as they cut, rub and plough along the workpiece. Because of this lubrication, the authors propose that the frictional forces exerted on the bonding material are lower and, therefore, one can increase the material removal rates until the forces cause the stresses to exceed the maximum allowable for the bonding material.

The coherent jet was able to achieve a maximum material removal rate of 1.97 cm^3/min and used 1.81 l of cutting fluid concentrate during a single creepfeed grinding pass. In comparison, the new system's results are summarised in Table 3.

Table 3 Results of new system

Concentration (Lube; coolant)	*Cutting fluid concentrate used (litres)*	*MRR (cm^3/min)*
2.5%; 2.5%	0.31	2.79
9.3%; 3.4%	0.73	3.11
17%; 3.7%	1.10	3.28
27.2%; 3.4%	1.58	3.61

As given in Table 3, the total cutting fluid concentrate used was determined using volume flowrates which can be calculated from Equation 3. Coherent jets tend to use relatively high flowrates at low coolant concentrations while the new system uses two cutting fluid streams (one at a high concentration and one at a low concentration) with considerably lower flowrates.

$$Q = C \times \frac{dQ}{dt} \times t \tag{3}$$

where Q is the volume of cutting fluid concentrate used; C is the concentration of cutting fluid; dQ/dt is the flowrate of cutting fluid stream; t is the time for grinding pass.

Equation 3 is applied to both the coolant and lubrication streams and then added together to obtain the total volume used during the grinding pass. Figure 20 compares the MRR and the amount of cutting fluid concentrate used to achieve the MRR. This figure clearly shows that the new system can achieve a higher material removal rate while using less cutting fluid concentrate.

Figure 21 shows the percent improvements between the new system and the coherent jet benchmark system. When the lubrication concentration is 2.5% and the coolant concentration is 2.5%, there is a 42% increase in the MRR when compared with the coherent jet. If the lubrication concentration is increased to 27.2%, there is an 83% increase in the MRR when compared with the coherent jet.

Figure 20 Fluid concentrate to MRR

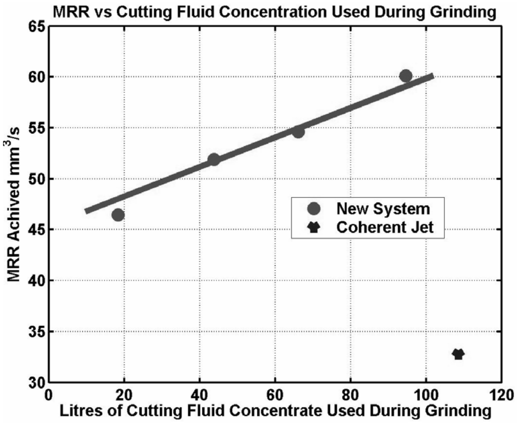
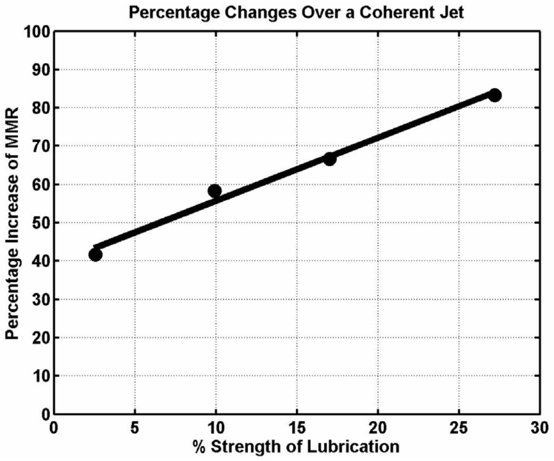


Figure 21 Percent increase of coherent jet



4 Summary

This paper develops and validates a new cutting fluid application technique for creepfeed grinding with aluminium oxide grinding wheels. The proposed system applies a high concentration synthetic cutting fluid to the grinding zone to lubricate the system, while a low concentration is delivered to the sides of the workpiece via coherent jets for bulk cooling of the workpiece. The two flows are kept separate using baffles and air scrapers even after they pass over the workpiece.

The new dual cutting fluid system was able to achieve an 83% increase in MRR over a state-of-the-art coherent jet and provide the capability of keeping the liquid cutting streams separate during creepfeed grinding.

If side coolant is applied, it appears that there is not a significant improvement in the grinding performance for the flowrates tested in this study. Further methodical investigation of the flowrates and orientations would help to better understand and optimise bulk cooling fluid application.

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