Fachausschuss
Maschinenbau,
Fertigungssysteme,
Stahlbau

Low-emitting metal working with minimum quantity lubrication

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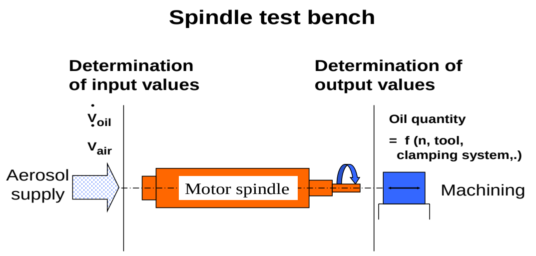
This Fachausschuss Information Sheet provides an overview of the study carried out by the committee of experts "Mechanical engineering, manufacturing systems, steel construction" (Fachausschuss Maschinenbau, Fertigungssysteme, Stahlbau) concerning emissions which occur during the metal working with minimum quantity lubrication. In addition, measures for low-emitting metal working are described as well as useful instructions for evaluating hazards at the workplace if minimum quantity lubrication is applied.

In the field of metal cutting, the minimum quantity lubrication is increasingly applied and has been established in the meantime as alternative to the conventional wet tooling. The user is offered a large range of required equipment and information on the market for the introduction of this new technology. The introduction of the minimum quantity lubrication contributes to considerable cost savings. Due to the drastic reduction of the cooling lubricant quantity in the sectors "maintenance" and "disposal", which cause the main cooling lubricant costs, there exists a great saving potential.

With regard to occupational safety, a considerable reduction of the cooling lubricant exposure in the inhaled air, on the employees' skin and at the workplaces is generally achieved compared with the wet tooling method.

However, the question about the occurring emissions at the workplace during metal working with minimum quantity lubrication is still not answered yet. In particular, the formation of decomposition and pyrolysis products due to the small lubricant quantities in conjunction with the expected high thermal stress [1], [2] has not been subject of detailed research up to now.



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1 Emissions occurring during the application of minimum quantity lubrication

In a joint project, headed by the Institution for statutory accident insurance and prevention (Berufsgenossenschaft), in cooperation with lubricant manufacturers and industrial companies and supported by the BG-Institute for Occupational Safety and Health (BGIA), the emissions during metal working with minimum quantity lubrication were examined [3]. In addition, measures for the reduction of emissions with minimum quantity lubrication were worked out which should assist in establishing a hazard evaluation and which are described in the following.

1.1 Laboratory tests

During the first phase of the project which was carried out in the (BGIA) laboratory, the selected lubricants for the minimum quantity lubrication were heated in synthetic air up to 400 °C, up to 800°C (pyrolysed) respectively and the volatile constituents were analysed [4]. The pyrolysis tests served a qualitative analysis of hazardous substances which may occur in case of thermal stress of the lubricants during the working in the field of tool / cutting.

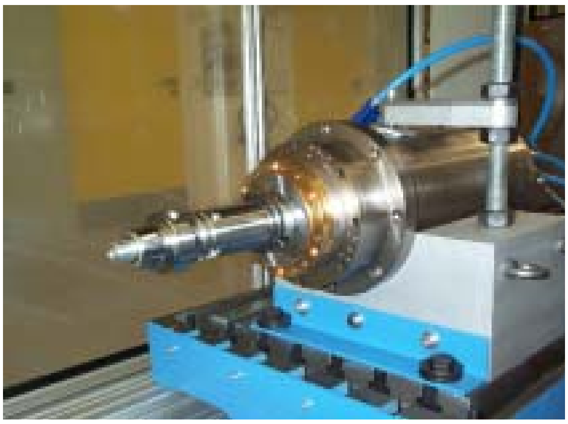

Figure 1: Spindle test bench with HSC-motor spindle for internal aerosol supply

During the pyrolysis tests of the lubricants applied in the laboratory, qualitative traces of saturated and unsaturated hydrocarbons, aldehydes and ketones were detected as well as saturated and unsaturated esters (C 16 – C 25) and superior alcohols (> C 15). However, the concentration of the detected pyrolysis products could be rated as very low with all tests.

1.2 Cutting trials at the spindle test bench

At a test bench of the Fraunhofer Institute for Chemical Technology, cutting trials were carried out by applying the minimum quantity lubrication with internal supply. The core of the test bench is a high-speed cutting (HSC) motor spindle with internal aerosol channel, a single axle traversing table for carrying out cutting trials and a force measuring platform for determining the cutting forces (figure 1).

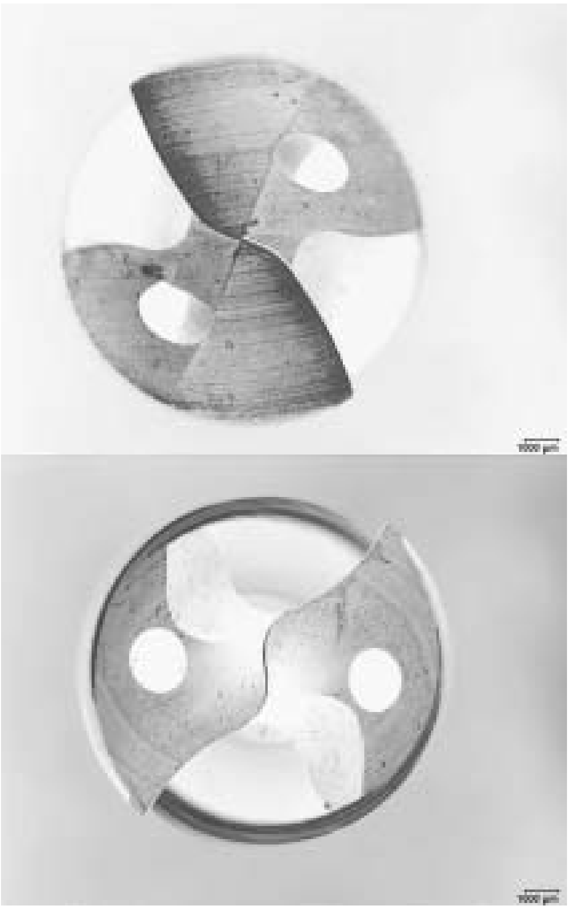

Figure 2: Applied twist drills for the dry tooling in the front view

For the cutting trials, the drilling method was chosen. These field trials were carried out by using different cutting parameters and materials (steel, aluminium and cast materials).

For this purpose, special twist drills for dry tooling with two internal cooling channels were applied (figure 2).

Two lubricant groups were tested. The first group was composed of pure synthetic diester oils of different viscosities with favourable tribological characteristics and a high thermal stress capacity. The second group included different lubricant finished products which are already applied in practice.

It was possible to determine and compare the emission tendency of different lubricants during the cutting process inside the test bench enclosure, directly at the place of formation under reproducible conditions.

1.2.1 Emissions during drilling

The following diagram shows the oil aerosol and diester oil values measured over a period of 15 minutes under field conditions (feed rate: = 800 mm/min) (figure 3).

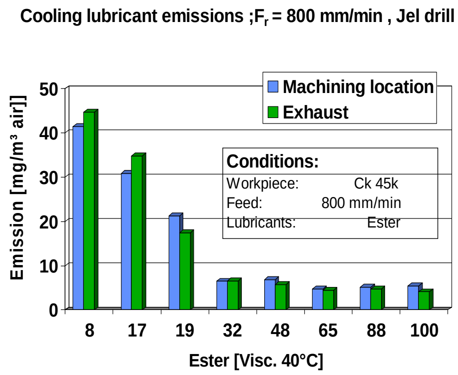

Figure 3: Oil aerosol and oil vapour emissions at the cutting location

During the cutting trials, in particular for the thin-bodied lubricants of low viscosity (< 10 mm^2/s at 40°C), a strong fog formation was determined. However, the high-viscosity esters of a viscosity greater than 20 mm^2/s at 40°C, showed considerably lower emission values.

The influence of the cutting parameters on the emission reaction of the lubricants is shown in figure 4 by means of examples for two selected feed rates. For this purpose, the feed rate was reduced from 800 mm/min (standard) down to 200 mm/min (extremely unfavourable) at a constant cutting speed.

During the machining with very unvavourable cutting parameters, the oil vapour and oil aerosol emissions increase abruptly. The reason for this is the high period in contact of the drill at a low feed rate in conjunction with an increased thermal stress of the lubricant.

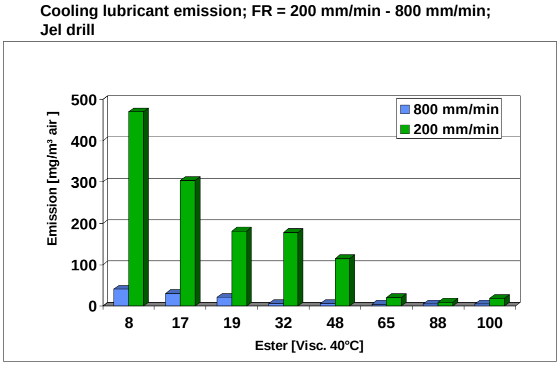

Figure 4: Emission values of oil aerosol and oil vapour at reduced feed rate

How decisive the selection of suitable lubricants and the optimum machining parameters are for a low-emitting minimum quantity lubrication is demonstrated in figure 5.

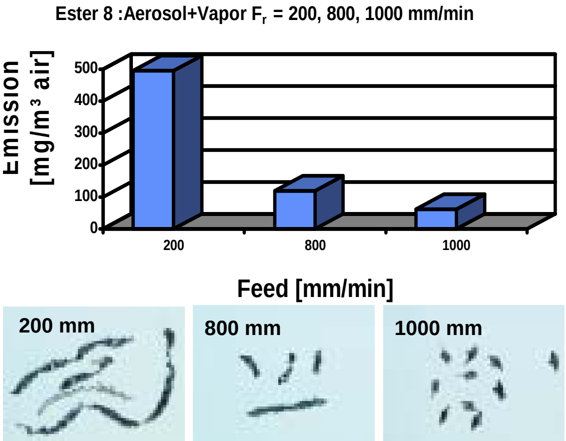

Figure 5: Variation of feed rate when applying the lubricant ester 8 with formation of chip shape

The machining under optimum working conditions owing to high feed rates, leads - apart from short discontinuous chips, a high cutting performance and a long tool life – also to the lowest emissions. However, unvavourab-le cutting conditions (by trials with extremely reduced feed) lead to high emissions with simultaneous unfavourable machining conditi-ons (resulting in long chips and high tool wear).

Recently, an increasing tendency could be noticed which is to apply thin-bodied media with a low flash point (< 100°C) which should evaporate as far as possible free from residue after the machining operation. In order to evaluate the emission reaction of those lubricants, an assay of very low viscosity was tested in comparison (3mm^2/s at 40°C). The result of this test is shown in figure 6.

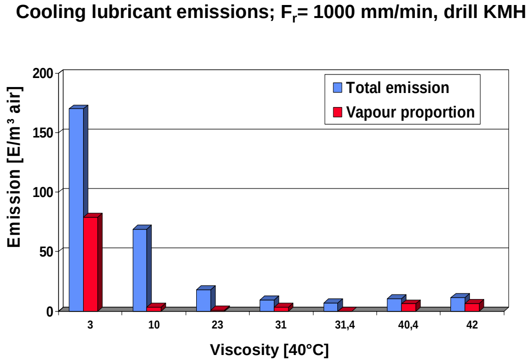

Figure 6: Cooling lubricant emissions finished products; feed rate: 1000 mm/min

The emissions measured at the oil of low viscosity exceed the values of the conventional products many times over. This shows clearly the negative effects of low viscosity products on the entire situation at the workplace due to their very high emissions – in particular due their increased portions of vapour. Therefore, the application of high viscosity products should be given preference.

1.2.2 Pyrolysis products during drilling

Under field cutting conditions, only a slight concentration of pyrolysis products was detected. In case of high thermal stress of the lubricant ("Worst Case" due to operating error, malfunction), higher values were measured. In this case as well, the high viscosity media showed a considerably lower tendency towards pyrolysis than the thin-bodied lubricants of low viscosity. However, the measured concentra-tions reach even in the immediate vicinity of the point of formation max. 0,1 mg/m^3 and can therefore be considered as uncritical.

It could be summarised that for all tested lubricants, even under extreme conditions with high thermal stress in the test bench, only a slight concentration of pyrolysis products was measured. The tendency to the creation of pyrolysis products with minimum quantity lubrication can therefore be classified as very low.

1.3 Exposure measurements in practice

Within the scope of a special measurement programme, exposure measurements at work-places with minimum quantity lubrication machining at machine tools were carried out during the production process. For this data collection, measurements were carried out at persons, stationary at the control panel of the machine as well as in the machine's interior working area (figures 7, 8) [3].

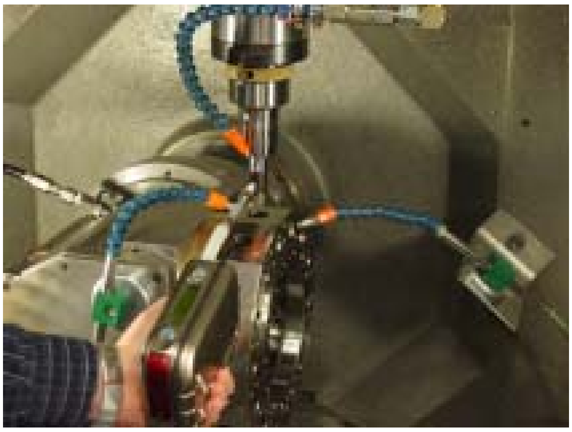

Figure 7: Determination of CO-concentration by measuring instrument with direct indication

During the cutting of materials with minimum quantity lubrication at machine tools during production, cooling lubricant vapours and cooling lubricant aerosols had proven to be the exposure determining component. Aldehydes (formaldehyde) were only determined in traces (<< 1% of air limit value) in particular cases.

Figure 8: Exposure measurements at persons and at the control panel

In total, 16 extensive series of measurements in the working area were carried out. In neither of the present cases, an exceeding of the air limit values was determined. The measured concentrations in the working area were that low so that for 11 cases the result "Steadily safe keeping of air limit value" and in 5 cases the result "Keeping of air limit value" could be granted [5]

The half of the determined measuring values were lying clearly below 15 % of the air limit value for cooling lubricants with 1,4 mg/m3. In 95 % of the cases, the half of the limit value of 5 mg/m^3 was not exceeded.

1.4 Summary

All those tests and findings showed that by means of an adequate application of minimum quantity lubrication, a low-emitting metal working with the reduction of skin-irritating potential is possible.

However, this requires a general assessment of the system. A safe machining process is only achieved if the elements lubricant, tool, metering device and machine are suitable for minimum quantity lubrication and coordinated in the best possible way.

A detailed description of further test results as well as information to the minimum quantity lubrication can be found in the project report "Hazard evaluation for the dry tooling of metal materials" The project report and the recommendation of BG/BIA with regard to the subject "minimum quantity lubrication" can also be downloaded on the Internet under http://www.bgmetallsued.de.

2 Information for low-emitting metal working with minimum quantity lubrication

The technical measuring service has prepared a BG / BIA recommendation for low-emitting metal working. This BG / BIA recommendation specifies the criteria for keeping the air limit values in the working area. Control measurements according to TRGS 402 [8] are not required if the following conditions are kept:

2.1 Selection of lubricants

For the low-emitting metal working with minimum quantity lubrication, the correct **selection of the lubricant** is of decisive importance. In order to minimise emissions, lubricants which are toxicologically and dermatologically safe should be applied, while having favourable lubricating properties and a high thermal stress capacity. Synthetic ester oils and fatty alcohols with low evaporation characteristics, being toxicologically harmless and with a high flash point have particularly proven themselves in practice [6], [8].

As reference values for the selection of a low emitting lubricant, in particular **flash point** (DIN EN ISO 2592) as well as the **Noack evaporation loss at 250°C** (DIN 51581 T 01) are proven. The lubricant should have a flash point of at least 150°C, an evaporation loss at 250°C of max. 65 % as well as a viscosity at 40°C (DIN 51562) of > 10 mm²/s.

Viscosity at 40°C DIN 51562 [mm²/s]	Flash point open cup DIN EN ISO 2592 [°C]	Noack evaporation loss 250°C DIN 51581 T 01 [%]
> 10	> 150	< 65

Table 1: Reference values for the selection of a low emitting lubricant

Not applied for the minimum quantity lubrication are:

- water mixed cooling lubricants and their concentrates
- lubricants with organic chlorine or zinc containing additives
- lubricants which have to be marked according to the Decree on Hazardous Materials
- products basing on mineral base oils in the cooling lubricant > 3 ppm benzpyrene
- native ester (rapeseed oil) tending to gumming at units, cheeks and ageing/ gumming due to low oxidation and hydrolysis stability.

2.2 Requirements for metering systems

Ensuring the continuous supply of the lubricant to the point of application without interruption is of particular importance for the process safety and the emission. For this reason, only safe systems which fulfil the following requirements have to be used for the supply and proportioning of the lubricant:

- Setting of parameters (e.g. quantity and pressure) according to standard values depending on the process, the material and the machining parameters.
- Precise and vibration-insensitive alignment of the nozzle(s) in relation to the point of application is possible.
- Monitoring of the minimum quantity lubrication function (e.g. lubricant level, transport of media and compressed air) possible
- Spraying characteristics of the nozzle:
    - Indication of favourable system setting points in order to minimize fog formation
    - Target-oriented wetting (indication of effective nozzle range)
- Indication of viscosity range at 40°C which can be applied in the system
- Loss free transport of media up to point of transfer nozzle or tool ensured (no leakages)
- Components and seals resistant to applied media according to the case of application
- Smallest adjustment for realization of dry workpieces and chips (scaling < 10 ml/h) possible
- Continuous lubricant medium supply (no stops, interruptions) ensured
- Fast response characteristics and media availability at the cutting point, even in case of longer rest periods
- Low noise generation in the factory (<75 dB [A])

2.3 Requirements for the tools

As basis for trouble-free and process-safe metal working, the selection of a suitable tool is of significant importance [7]. Therefore, adequate tools should be applied for the minimum quantity lubrication which are released by the manufacturer. This requires the cutting parameters, specified by the tool manufacturer to be kept (rotational speed, cutting speed, feed).

2.4 Skin protection

By applying the minimum quantity lubrication, a reduction of skin-irritating potential can be achieved in comparison to the conventional wet tooling.

If direct skin contact to cooling lubricants cannot be avoided, suitable skin protection measures shall be taken:

– Prepare a skin protection plan (skin protection plan B for non-water mixable cooling lubricants according to BGI 658).
– Avoid skin contact by applying auxiliary tools.
– Protect exposed skin parts by protective clothing (BGR 189).
– Use of durable protective gloves, provided there is no work carried out at rotating machinery (BGR 195).
– Provide skin protection-, skin cleaning- and skin care products (BGR 197).
- Training of employees with regard to the use of skin protection products.

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