Chapter 6
Cutting Fluids

6.1 The Functions of Cutting Fluids

By fulfilling its main functions, cooling and lubricating the machining site as well as carrying away the chips, modern cutting fluid systems make a substantial contribution to the high performance level of many manufacturing processes. This is achieved by removing process heat from the tool/workpiece contact area by cooling and slowing the progress of heat via lubrication. Not only must excessive heating of the workpieces, which leads to expansion, be avoided, but also temperature load on the cutting tool material be reduced. The fulfilment of these functions may at first sound simple, but often requires cutting fluid properties which are not readily combined with each other.

6.2 Types of Cutting Fluids

According to DIN 51385, cutting fluids are classified as non water-miscible, water-miscible or water-based. Water-based cutting fluids are fabricated simply by adding the water-miscible concentrate to water (Fig. 6.1).

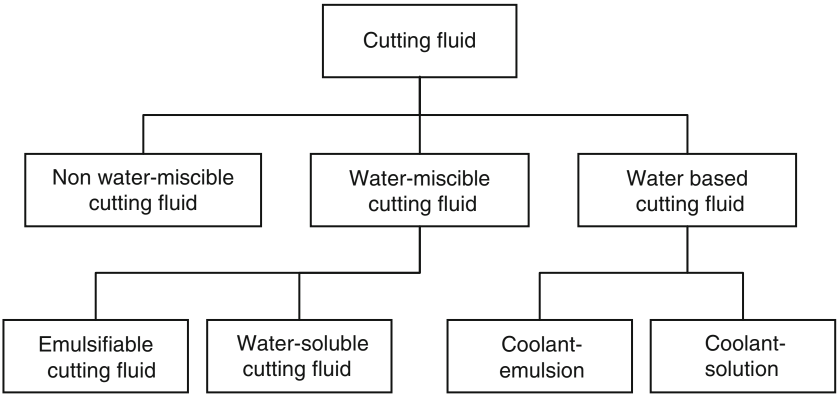

Fig. 6.1 Division of the most important metalworking cutting fluids, acc. to DIN 51385

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6.2.1 Non Water-Miscible Cutting Fluids

Non water-miscible cutting fluids are mostly mineral oils that contain additional active agents to improve lubrication, wear protection, corrosion protection, durability and foaming properties. Additives that improve lubrication ("antiwear additives" or AW-additives) help to reduce friction at the cutting location. To this end, natural fat oils (palm oil, rapeseed oil) or synthetic fatty substances (ester) are added. The polar structure of these additives gives the additives good adhesive properties on the metal surface, on which they form a half-solid lubricating film called "metal soap". However, the effectiveness of this lubricating film is reduced in temperatures higher than its melting point (120–180°C). EP-additives (EP = extreme pressure) are also added to the mineral oils. Compounds containing phosphorous and sulphur as well as free sulphur are used. The chlorine compounds also shown in Fig. 6.2 are now of secondary importance in Germany. Burning used cutting fluids containing chlorine is now only allowed in special incineration sites, since toxic dioxins can possibly be generated in case of uncontrolled burning. This makes disposal much more expensive, so additives containing chlorine are largely avoided. On the metal surface, the additives form metal salts at different temperatures. These salts can absorb high pressures and exhibit only a low level of shear strength. In this way, not only are forces lowered but also heat arising at the cutting location is reduced. The temperature spheres of action of the individual additives can be seen in Fig. 6.2.

In addition to mineral oils, low-viscosity ester oils are also used as cutting fluids in machining. Presently, mostly mineral oils (about 90%) are utilized. The reason for this is the lower cost required to procure it in comparison to synthetic ester oils. This

Kind of additive		Temperature sphere of action
Lubrication improving additives	Fatty oils (animal, vegetable)	until ca. 120 °C
	Synthetic Fats (ester)	until ca. 180 °C
EP-additives	Chloric compounds	until ca. 400 °C
	Phosphoric compounds	until ca. 600 °C
	Sulfidic compounds	until ca. 800 °C
	Free sulfur	until ca. 1000 °C

Fig. 6.2 Temperature range of coolant additives (Source: Mobil Oil)

advantage of mineral oils compared with synthetic ester oils is however becoming increasingly smaller due to the steady increase in raw oil prices in the last several years. Compared with mineral oils, ester oils are characterized by a lower evaporation tendency, a higher flash point, more favourable lubrication properties, they are skin-friendlier and they are biologically more degradable [Frei00]. Although ester oils have much better lubrication properties in comparison to mineral oils because of their polar chemical structure, as a rule tribologically active, surface-active additives in the form of phosphorous or sulphur compounds are also added to them to improve these properties further. These additives reduce friction and wear, but they reduce the biological degradability of the oils considerably.

With this in mind, the goal of current research [Murr07] is to develop a quickly biodegradable family of fluids based on renewable raw materials that fulfils all of the cooling and lubricating functions required in a machine tool. That means, non-additive ester oils should not only be used as a cutting fluid in machining, but as lubricating and pressure transmission media in all other tribosystems of a machine tool. The loss of tribological functions of the lubricating medium caused by dispensing with additives should be compensated by appropriate PVD wear protection coatings, i.e. the functions of the cutting fluid should be relocated to the tool surface [Krie01, Kloc06a].

6.2.2 Water-Based Cutting Fluids

Emulsifiable cutting fluids are supplied as a concentrate and thinned with water to become emulsions prior to use. The high amount of water used (up to 99%) is the cause of the good cooling effect of emulsions, but they further corrosion for that reason as well. The fluid's lightly alkaline character (pH-value of 8–9) helps protect against rust. Higher alloyed emulsions contain the additives shown in Fig. 6.2 to improve lubrication and compressive strength. Infestation by micro-organisms such as bacteria, yeasts and fungi are a major problem in emulsions. The result is a decreased pH-value and thus also a reduction of the fluid's ability to protect against corrosion. There is also an odour nuisance and hygienic conditions for the operating staff are worsened. In addition, the emulsion becomes unstable, i.e. oil is deposited on the surface, and deposits are formed that clog the filter and thus lead to malfunctions. Biocides, which are added to the emulsion at a percentage of about 0.15%, provide a remedy to this. If this value is significantly exceeded, it can lead to dermatological problems in the personnel, while a percentage that is too low has no effect.

The most important coolant additives are emulsifiers. They have the function of dispersing the oil in the water so that a stable oil-in-water emulsion is produced after mixing with water. A distinction is made between ionogenic and non-ionogenic emulsifiers. They form a relatively stable film on the boundary surface between the oil droplets and the water, which prevents the oil droplets from coalescing. Examples of emulsifiers include, for example, alkali soaps of fatty acids or naphthenic acids (ionogenic) and reaction products of alkylphenols and athylene oxide.

The amount of emulsifier determines the size of the oil droplets. In the case of the coarsely dispersed emulsions used in metalworking, this amount is between 1 and 10 μm [Mang01].

Cutting fluid solutions are produced by mixing a water-soluble concentrate with water. They are not generally used for cutting with geometrically defined cutting edges. Their main area of application is in grinding.

6.3 Guidelines on the Use of Coolant Emulsions

When coolant emulsions are used, there are some guidelines that should be considered in order not to impair their stability and performance. As the main component of the emulsion, the quality of the water is of decisive importance. The hardness of the water, its most important property, is the result of the content of water-soluble calcium and magnesium salts. It is given in °dH (degree of German hardness) or mmol/l (1°dH = 0.179 mmol/l). The water's hardness should be between 5 and 20°dH. If the water is too hard, the emulsifiers react with the calcium and magnesium salts, which leads to the formation of water-insoluble soaps (creaming on the emulsion surface) and reduces the emulsifier content. The useful life of the emulsion is shortened drastically by this. Soft water on the other hand promotes unwanted foaming.

There are further water requirements concerning nitrate and chloride content. In general, drinking water quality is sufficient in order to keep the initial load on the emulsion by bacteria, yeasts and fungi at a low level. The nitrate content should not exceed 50 mg/l.

When applying coolant emulsions, the water must first be added to the container, then the concentrate. The mixing process should always be carried out with vigorous stirring so that a good oil-in-water emulsion without flocculation is formed.

One test point of the finished emulsion is concentration. This can either be done with a hand-held refractometer or an emulsion test flask. With the hand-held refractometer, the concentration can be quickly determined on the spot. It utilizes and displays the relation between the refraction index and concentration. A more exact method consists in separating oil and water in a test flask by adding hydrochloric acid. The disadvantage of this method is that it is more time-consuming.

The pH-value of emulsions should in their freshly prepared state be between 8 and 9. This is tested in practice usually with indicator paper, the coloration of which when dipped into the fluid serves a measure of pH. Potentiometrical determination of pH is only recommendable when higher precision is required.

During operation, impurities such as chips or dust constantly get into the cutting fluids. They need to be removed from the emulsion, as they have a negative effect on tool life and the manufacturing product in addition to clogging the pumps. In order to get rid of impurities, one can choose between gravitational purification in sedimentation tanks, centrifugal force purifiers (e.g. centrifuges, separators), magnet filters or various designs of belt filters.

When changing the coolant, one should always carefully clean the container, since nests of bacteria immediately infect the new filling, significantly reducing the service life of the emulsion. System purifiers or hot water jet devices have proved effective in this task. Disposal of the coolant is a major cost factor. The separation of the oil from the water necessary to do this can be accomplished chemically (salt or acid separation), by ultrafiltration (membrane technology) or by vaporization/incineration.

6.4 Effects of the Cutting Fluid on the Machining Process

As explained in more detail in Chap. 3, the tool is exposed to very high mechanical and thermal loads during the cutting process, whereby the mechanical energy created to form the chips is almost completely converted into heat in the shear and friction zones. The result of these loads are wear phenomena such as mechanical wear and the shearing off of adhered materials, both of which occur within the entire effective cutting speed range, as well as diffusion processes and scaling – effects which manifest themselves only above certain temperatures (Sect. 3.7).

By virtue of their lubricating effects, cooling fluids primarily influences adhesive wear, which occurs due to the periodical migration of built-up edges within certain speed ranges [Opit70a, Köni66, Prim69]. Especially wear phenomena associated with adhered material particles in the lower speed range (when using HSS) can be effectively countered with lubrication.

To counteract surface pressure, there should be solid layers with high compressive strength and low shear strength on the metal surface, which prevent a direct sliding of materials into each other. This can stop or at least reduce welding. If necessary, this can be accomplished with high pressure additives in the cutting fluid. However, one must bear in mind that sulphur or phosphorous additives only become effective at certain temperatures, and for this reason the composition of the lubricant must be calibrated to the respective operation. The most important prerequisite is that the lubricant has access to the contact zone. In the range of increased built-up edge formation, this condition is met by the fluctuation of the built-up edges.

As the cutting speed increases – in the range of reduced built-up edge formation – the conditions for the formation of high pressure lubricating films becomes progressively more unfavourable because the increased chip flow shortens the time for potential reactions between the additives and the metallic surface. At the same time, the increase in temperature leads to diffusion phenomena between the friction partners or, in the extreme case, to plastic deformation of the cutting edge, making it necessary to cool down the cutting area. Accordingly, at these speeds begins the range in which tool life is improved not so much by the lubricating effect of a fluid but by its ability to remove heat, i.e. by cooling.

On the other hand, it is thoroughly possible that wear on the tool is considerably increased by the cooling and the tool life is accordingly reduced. This is clarified in Fig. 6.3. There is much more crater wear in wet cut than in dry cut operations. By cooling, the temperature of the flowing chip is lower and thus its strength is

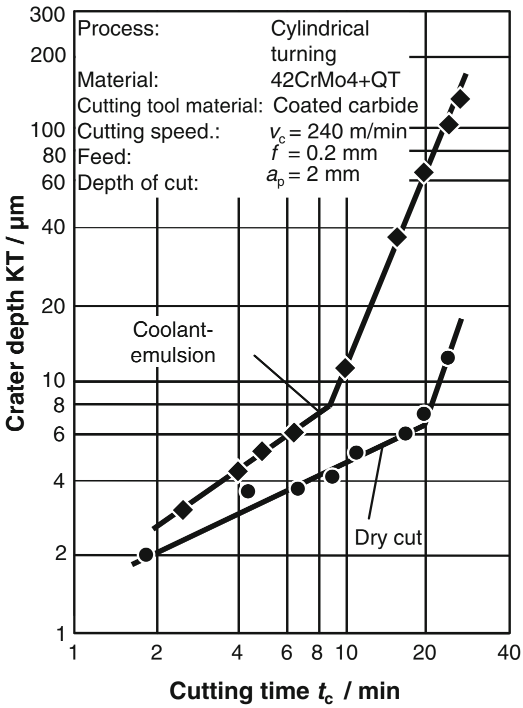


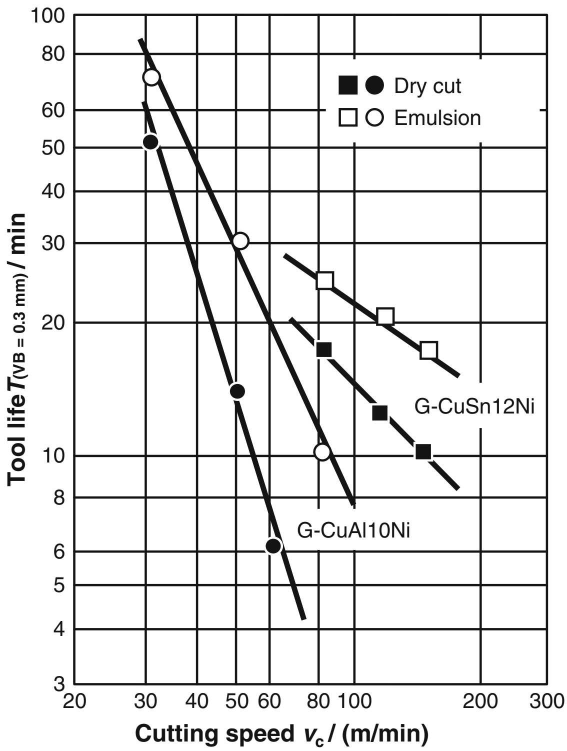
Fig. 6.3 Wear-cutting time diagram for dry cut and with application of cutting fluid

higher, which manifests itself in increased forces. Since the cutting fluid mainly cools the top of the chip, and the bottom of the chip remains largely unwetted due to its intense contact with the rake face, a larger temperature gradient is formed in the chip as in the uncooled process. This results in a larger chip curvature, so that the contact surface between the chip and the tool is reduced in size. On the whole therefore, there is an increase in the specific stress on the rake face and consequently more crater wear.

One must also consider machining operations with low cutting speeds, which generally are designed so that the built-up edge range is avoided. But when cooling lubricants are used, the temperatures prevailing during the formation of built-up edges shift to higher cutting speeds, so that a process optimized for uncooled cutting may be incorrectly designed [Opit64].

On the other hand, we can expect clear improvements in service life when the cutting temperature is near the softening point of the cutting tool material without the use of a cutting fluid. Figure 6.4 shows how effective the cooling effect of an emulsion is in this case using the example of drilling copper alloys with HSS drills. The use of emulsions permits higher cutting speeds and larger feeds and a significantly augmented tool life [Bömc85].

A further aspect to be taken into consideration is the transport of chips from the cutting area. For example, it can be advantageous when groove milling with



Tool: Twist drill (d = 11 mm)
Cutting tool material: HS6-5-2-5

Material:	G-CuAl10Ni		G-CuSn12Ni	
	dry	wet	dry	wet
Feed:	f = 0.1 mm	f = 0.2 mm	f = 0.2 mm	f = 0.4 mm
Drilling depth:	l = 30 mm	l = 30 mm	l = 45 mm	l = 45 mm

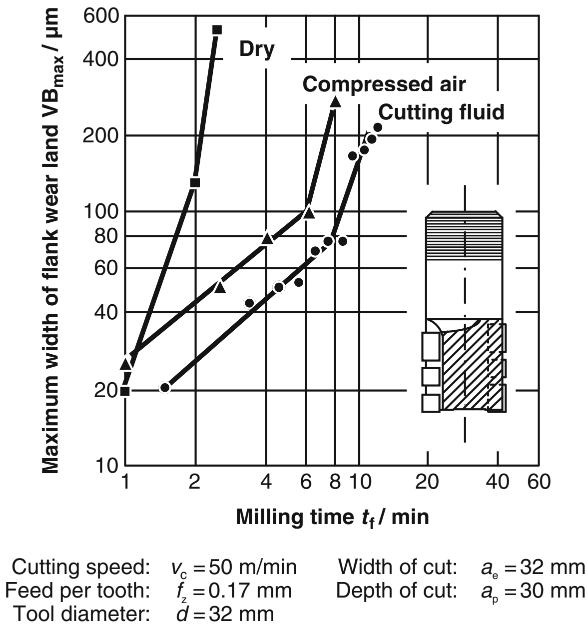
Fig. 6.4 Influence of cooling on tool life during the drilling of copper

cemented carbide-fitted shaft millers to remove chips from the cutting edge with compressed air or cutting fluid so that no chips are pulled into the cut, increasing wear. The disadvantage that cooling increases temperature change stress on the indexable inserts is more than compensated by this (Fig. 6.5) [Köll86].

When drilling, the cutting fluid also fulfils the main function of leading chips out of the drill hole and thereby helping to avoid any clogging of the flutes.

Some machines are designed in such as way that specially arranged nozzles clean the working space with cutting fluid so that chips do not hinder subsequent operations or impede the clamping of new workpieces.

Fig. 6.5 Time course of wear during groove milling of titanium in dry cut and wet cut with external compressed air



6.5 Selection of Cutting Fluids

As a summary, those aspects of cutting fluid selection will be mentioned that are of significance from a technological and economical point of view.

Emulsions are characterized by a number of properties that predestine them as cutting fluids for use in machining, above all their favourable cooling and cleansing effect as well as the low purification cost for workpieces, tools and chips (Fig. 6.6). Their high cost of maintenance and the working area and environmental problems associated with their use have led to emulsions being replaced with non-water soluble cutting fluids [Kloc96a].

Oils are already being used as cutting fluids in many areas, for example in processes for manufacturing tooth systems, broaching and high-speed grinding with PCBN. The advantage of non-water soluble cutting fluids is on the one hand their technical properties – particularly their good lubricating effect – but especially their much lower maintenance and disposal costs compared with emulsions. Their service life is practically unlimited. Only the discharge need be replaced. From the standpoint of occupational health, the superior skin-compatibility of oils is another essential advantage.

The use of non-water soluble cutting fluids is however also associated with a series of disadvantages, such as higher maintenance and refilling costs. The higher viscosity of oil requires an adjustment of the machine with respect to the cutting fluid and filters. The strong tendency to form vapour and mist requires a complete enclosure of the machining area with corresponding suction. The good adhesion

	Oil	Emulsion
Consumption	10%	90%
Cooling effect	low	very good
Lubricating effect	very good	low
Skin compatibility	good	problematical
Bacteria tolerance	good	less good
Water endangering class	WGK 1–2	WGK 3–4
Preparation costs	high	low
Maintanance costs	low	high
Service life	unlimited	2 –24 Months
Disposal costs	low	high
Resultant wastewater	very low	very high
Machine compatibility	good	problematical
Corrosion protection	good	low
Fire protection requirements	high	not necessary
Effort for workpiece and chip cleaning	high	low
Reuse of cutting fluid	possible	not possible

Fig. 6.6 Advantages and disadvantages of using oil or emulsion as cutting fluid

of the oil to the workpieces leads to large drag-out losses, demands long periods of draining in basins as well as extensive turning, spinning and cleansing of the workpieces. The chips must also be spun and, if necessary, washed. Moreover, oil vapour and mist can form a combustible mixture with air, leading to deflagration.

In conclusion, a general statement regarding the economical use of this or that cutting fluid must be made on a case-by-case basis.

6.6 Reducing or Avoiding the Use of Cutting Fluids

Besides the technological benefits provided by cutting fluids, they also represent a considerable hazard to the environment and humanity. Cutting fluid components such as bactericides and fungicides, reaction products originating in the cutting fluid and included foreign substances can all become the root cause of illnesses. Leakage and drag-out losses, emissions, wash water and the disposal of used cutting fluids are a burden on earth, water and air.

The handling of cutting fluids and their disposal is therefore being regulated by lawmakers and professional associations with strict requirements. Guidelines regarding cutting fluid requirements and associated devices, regarding maintenance and disposal of the fluids and regarding the laws, regulations and the requirements and rules of professional associations are given, among other places, in BG rule 143, VDI guideline 3397 and the VDMA brochure "Cutting Fluids – Fresh Air at the Workplace" [VDMA 2002]. For companies, these regulations and requirements mean not only great responsibility towards their workers but in particular growing financial burdens. For manufacture, the task of satisfying requirements concerning environmental protection without putting the profitability of the production in danger is becoming increasingly crucial. An approach for this purpose represents the reduction or the avoidance of the cutting fluids use.

6.6.1 Reducing Cutting Fluids

A reduction of the use of cutting fluids aims to make avail of only the technologically necessary amount of cutting fluid. Secondary tasks of the cutting fluid, such as chip transport within the machine or bringing those chips to the right temperature must be executed by other measures which concern not only the tool but also the machine tool (Fig. 6.7) [Köni93a].

There are different possibilities for the machine tool. In order to transport chips, inclined machine bed concepts, conveying systems, special chip guiding systems

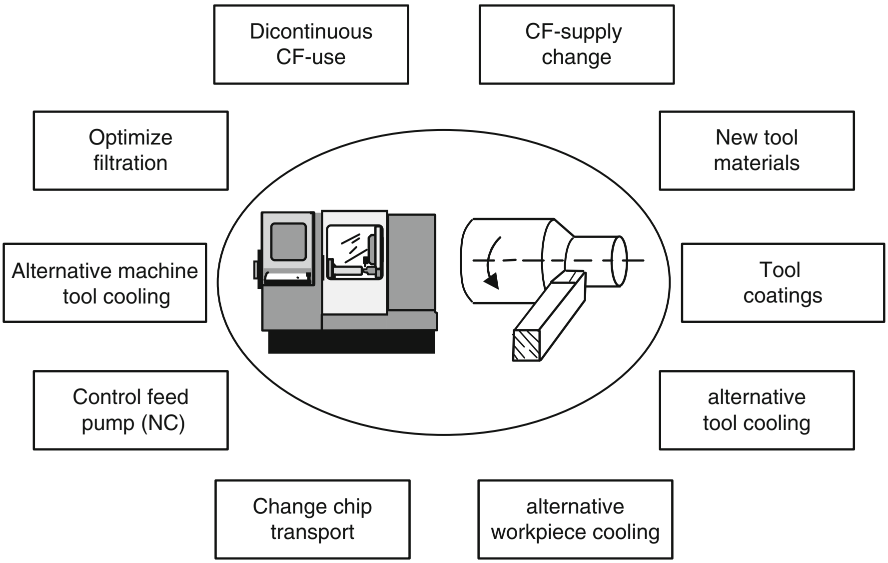


Fig. 6.7 Tool and machine related means of reducing the demand of cutting fluid

or other alternative media (e.g. compressed air) can be used. The machine tool's temperature consistency, important for form and dimensional tolerance, can be achieved, for example, by means of closed cooling cycles.

With respect to tools, there are a number of different approaches for reducing the amount of cutting fluid used. One example is the internally cooled tool. Besides drills with cooling ducts, which have been state-of-the-art for a long time, indexable inserts with "internal" cutting fluid supply are also being used. The cutting fluid is supplied directly to the cutting area by a duct in the supporting tool and the insert. This more effective cutting edge cooling requires not only a significantly lower volume of cutting fluid, but also has, in grooving and parting-off operations, a positive effect on tool wear, tool life, chip removal and the surface quality of the workpiece [Köni93a].

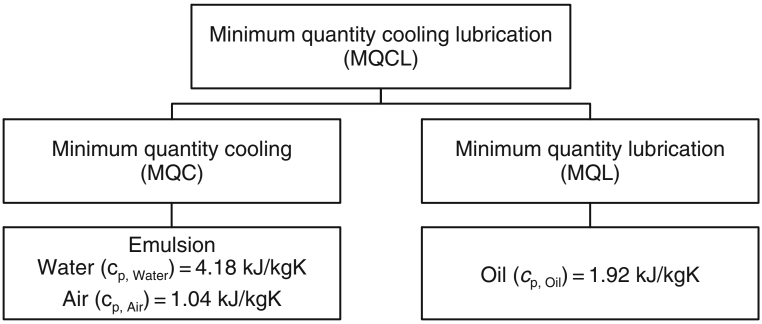
6.6.2 Minimum Quantity Cooling Lubrication (MQCL)

A further measure to reduce the amount of the cutting fluid represents the so-called Minimum Quantity Cooling Lubrication (MQCL) [Kloc96a, Köni93a, Wein04]. In this cutting fluid technology, the tools are supplied with the smallest amounts of a coolant and/or lubricant. Usually, oils are used, but also emulsions, water or air. They are supplied to the tool and/or cutting area in the smallest possible quantities. This is achieved either with or without a transport medium. In the case of "airless" systems, the tool is supplied by means of a pump with a medium in the form of individual, rapid, successive finely dosed droplets, usually of oil. In the second case, the medium is atomized into ultrafine droplets with the help of compressed air in a nozzle and supplied as an aerosol to the machining location.

In the sphere of dry machining, minimum quantity lubrication is generally understood as the supply of a cooling lubricant medium in the form of an aerosol. Depending on the type and primary task of the added medium, we can draw a distinction between a minimum quantity lubrication (MQL) and a minimum quantity cooling (MQC) (Fig. 6.8).

When oils are used, it is their good lubricating effect that stands in the foreground. Their task is to reduce friction and adhesion processes between the workpiece, chip and tool. By reducing friction, there is less frictional heat. The result is less heating of the tool and component in comparison to pure dry machining (Fig. 6.9) [Eise00]. Due to the low thermal capacity of oil ($c_{\mathrm{p,oil}} = 1.92\,\mathrm{KJ/kgK}$) and air ($c_{\mathrm{p,air}} = 1.04\,\mathrm{KJ/kgK}$) and the small quantity applied, the direct cooling effect of the oil/air mixture is of only secondary importance. Because of the very small cooling effect of the oil/air mixture, the use of oil as a medium is referred to as a minimum quantity lubrication (MQL).

In comparison to oils, emulsions or water are used as media for minimum quantity cooling lubrication much less often. They are generally only used when the tool or component must be cooled more intensively than is possible with oils. Due to the much lower lubricating effect of emulsions and water's complete lack thereof, the use of these media are also referred to as minimum quantity cooling (MQC).



Medium	Cooling	Lubrication	Chip transport
Emulsion	very good	good	good
Oil	very good	very good	good
Compressed air	limited	nothing	limited

Fig. 6.8 Definition of "minimum quantity cooling lubrication"

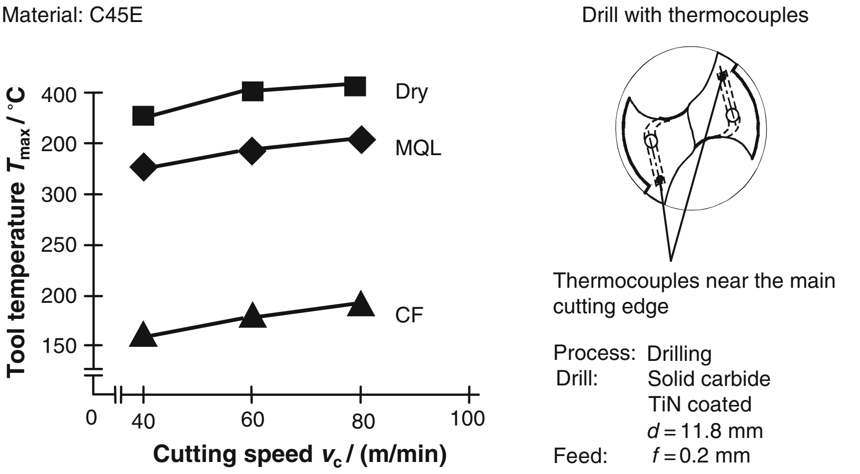


Fig. 6.9 Influence of minimum quantity lubrication on the tool temperature

Minimum quantity cooling (MQC) with emulsions, water (with a corrosion inhibitor), cold air or fluid gases is still a relatively seldom used component of minimum quantity cooling lubrication technology (MQCL) and is thus little known to users. MQC technology can however most certainly make a contribution to solving thermal problems in the tool or component in dry machining operations.

Due to their great importance in dry machining, the following remarks are concerned exclusively with minimum quantity lubrication technology (MQL). The

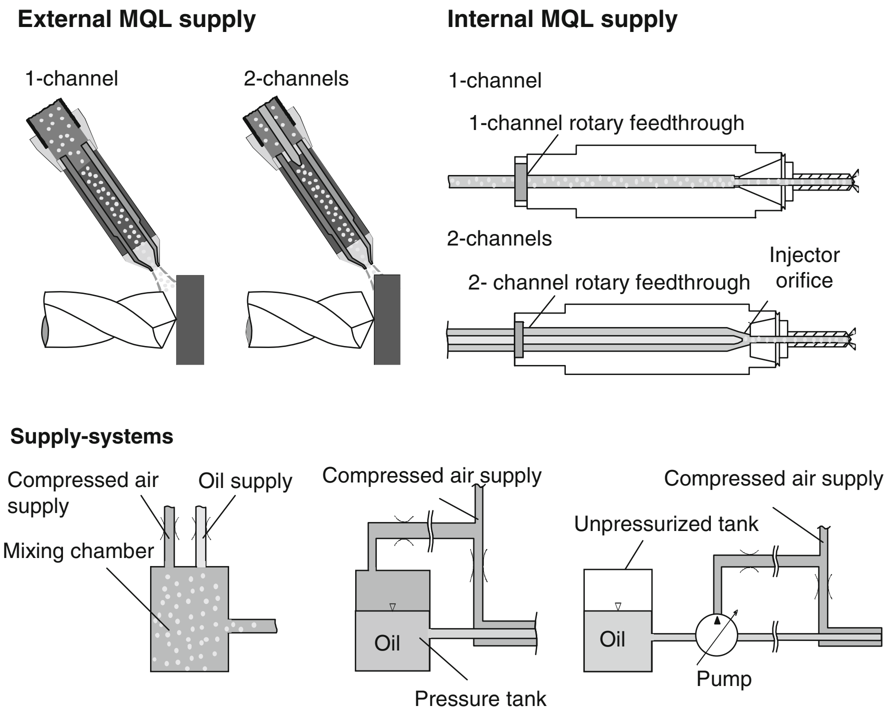


Fig. 6.10 MQL supply systems

MQL medium can be supplied to the cutting area from the outside by means of nozzles affixed separately in the machine space or by means of the tool spindle and internal cooling ducts inside the tool (Fig. 6.10). Both systems have their fields of application. In optimally adjusted MQL systems, less than 50 ml/h of the lubricating medium is used. Measured by the fact that up to 6 m^3 cutting fluid can be discharged daily in the case of a transfer line with a cutting fluid volume of 60 m^3, this means an enormous reduction of the quantities used in MQL technology. The essential feature of MQL is that, when correctly used, the tools, workpieces and chips all remain dry.

In the case of external supply, the aerosol is sprayed onto the tool from the outside with one or several nozzles. The number and orientation of the nozzles as well as the spray pattern, which is dependent on the nozzle design, all have a significant effect on the result. This method is used, for example, in sawing, shaft and knife head face milling and also in turning. In the case of internal machining operations, such as drilling, reaming or tapping, external supply of the medium is only practical up to length/diameter ratios of $l/D < 3$. For larger l/D ratios, the tool has to be retracted for a rewetting several times if necessary, which can lead to a considerable elongation of the machining process. The use of external supply is also problematic in machining tasks in which tools are used that vary significantly with respect to length and diameter. The supply nozzles need to be manually aligned or with the help of positioning systems, which, linked with the machine control, move the nozzles in an axial or radial direction or pivot them by a certain range of angles depending on the tool length and diameter. External MQL supply can however also be indispensable if the tools used do not have internal cooling ducts.

In the case of drilling, reaming and tapping with larger l/D ratios, internal supply of the medium by means of a spindle and the tool is advantageous, since the medium is continuously available near the cutting area independently of the drilling depth, and chip removal from the drill hole is supported. This is also similar for tools with highly varied dimensions. In the case of deep-hole drilling, internal MQL supply is indispensable because of the large l/D ratios. Further advantages of the internal supply of a MQL medium is that positioning fields such as are seen when nozzles are used, are avoided, and the integration of the MQL into the machine tool does not require the working space to be restricted by feed lines.

With internal MQL supply, we make a further distinction between 1-channel and 2-channel systems (Fig. 6.10). In the case of the 1-channel variant, the aerosol is produced outside the spindle and supplied by the latter to the tool. In 2-channel systems, oil and air are conveyed separately by the spindle. The air-oil mixture is produced directly in front of the tool. The essential requirement of both system variants is that the medium be available at the cutting location at the moment the cut begins in sufficient quantity.

Internal MQL supply requires tools with cooling ducts. Currently, drilling tools of < 1 mm diameter with internal cooling ducts are already available. In the case of tools without internal cooling ducts – be it drills, tappers or end milling cutters – external MQL supply is absolutely essential. But even in this case, tool manufacturers are offering special solutions that make it possible to conduct the MQL medium flowing through the spindle within the tool holder outside and then on the tool circumference lengthwise to the machining location.

The media used in MQL are primarily fatty alcohols and ester oils (chemically modified vegetable oils). Medium selection depends on the type of supply, the material, the machining method and the aftertreatment of the component (annealing, coating, varnishing).

In many material/method combinations, the use of a minimum quantity lubrication is vital to the realization of a dry machining operation (Fig. 6.11). From the standpoint of the material, this is especially true for dry machining aluminium wrought alloys, and from the methodological standpoint, largely independently of the material, for drill hole manufacture and drill hole aftertreatment. The classic application area for MQL technology is sawing. Due to the high hot wear resistance of the coated cemented carbide tools available today, the turning and milling of steel and cast iron materials are done to a large extent completely dry.

Figure 6.12 shows the effect of MQL on the tool's condition and tool life quantity when drilling into an aluminium wrought alloy. In the case of dry machining without MQL, the tool was already unusable after 16 holes due to material adhesion in the flute. When MQL was used, neither wear nor adhered material could be detected after 128 drill holes.

Material	Aluminium		Steel		Casting
Process	Cast alloy	Wrought alloy	High alloyed steel, bearing steel	Maching steel, heat-treatable steel	GG20 – GGG70
Drilling	MQL	MQL	MQL	MQL / dry	MQL / dry
Reaming	MQL	MQL	MQL	MQL	MQL
Thread cutting	MQL	MQL	MQL	MQL	MQL
Thread moulding	MQL	MQL	MQL	MQL	MQL
Deep hole drilling	MQL	MQL		MQL	MQL
Milling	MQL / dry	MQL	dry	dry	dry
Turning	MQL / dry	MQL / dry	dry	dry	dry
Hobbing			dry	dry	dry
Sawing	MQL	MQL	MQL	MQL	MQL
Broaching			MQL	MQL / dry	dry

Fig. 6.11 Application of MQL

6.6.3 Avoiding Cutting Fluids

The most decisive step in the avoidance of problems associated with the use of cutting fluids is dry machining. Many machining tasks, that still use large quantities of cutting fluids today do not technologically require them. For every current or future machining task therefore, the basic question should be posed of whether one can dispense with cutting fluids or not.

This cannot however simply be realized by stopping the cutting fluid supply, even if this brings about a positive effect in isolated cases. A sensible and economically viable dry machining operation demands a very thorough analysis of given restraints as well as an understanding of the complex relations that interconnect the process, cutting tool material, component and machine tool (Fig. 6.13) [Kloc98, Tham98, Adam02, Wein04].

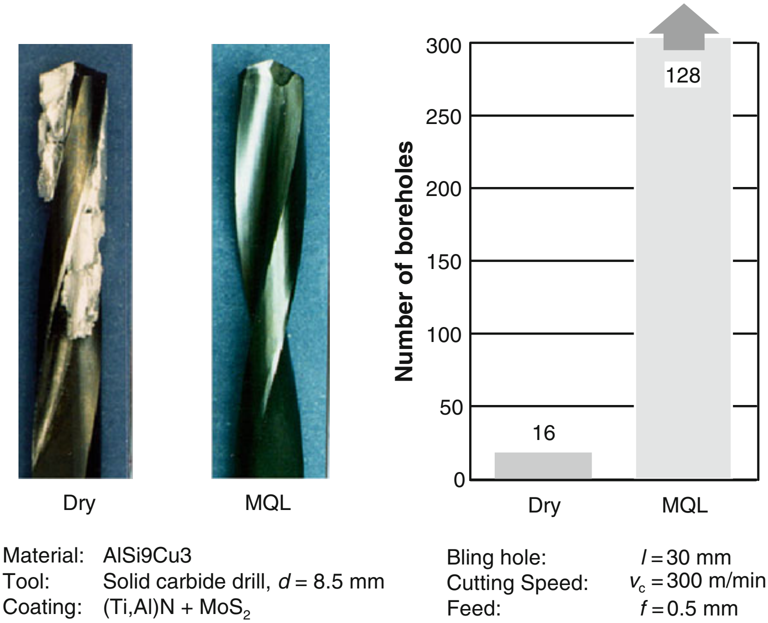


Fig. 6.12 Drilling of aluminium with and without minimum quantity cooling lubrication

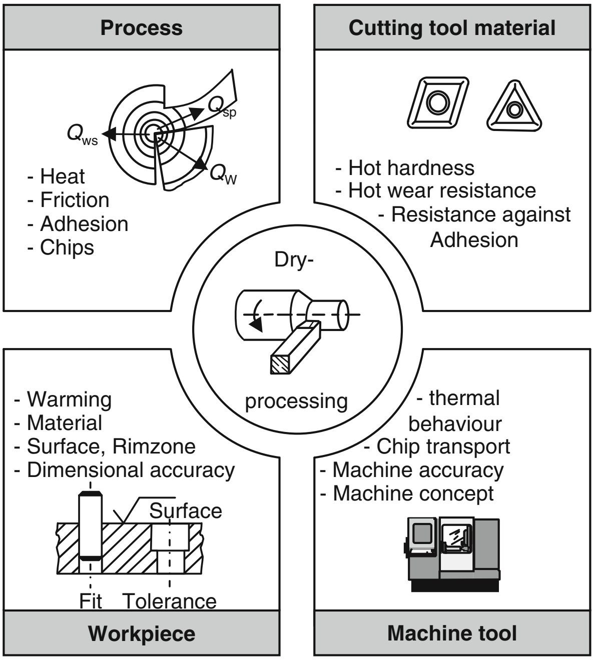


Fig. 6.13 Dry processing – requirements and constraints

In dry machining, the primary cutting fluid functions of lubrication, cooling and cleaning and rinsing, are omitted. This means for the cutting process on the one hand that stronger frictional and adhesive processes can take place between the tool and the material. It also means that part of the heat produced in energy conversion locations and dissipated by the chip, tool and workpiece is no longer absorbed by the cutting fluid and hot chips are no longer rinsed out of the cutting area or the machine tool. The consequence of this is higher thermal loading of the tool, component and machine tool, which in turn has a negative effect on tool life and component/machine precision. When planning and designing single processes or manufacturing sequences without cutting fluid, the goal must therefore be not only to lay the technological foundations, but to create the prerequisites necessary for dry machining from the standpoint of the component and the machine tool.

At present, cutting materials provide the best basis for dry machining. Cemented carbides, cermets, cutting tool ceramics and polycrystalline boron nitride have sufficient hot wear resistance to be used without cutting fluids. Tool coating is particularly important in this regard. This reduces the thermal load on the substrate and reduces frictional and adhesive phenomena between the material and the cutting tool material. Dry machining also leads however to an alteration of the heat flows between the tool and the chip. Since there is no cutting fluid to absorb the heat, more heat must be dissipated by the chip with a comparable heat conversion. This requires in turn that the hot chips are removed as quickly as possible from the working space by a suitable machine tool concept [Kloc98].

While we can do without the use of cutting fluids in many cases in turning and milling cast iron materials, steels, aluminium alloys and non-ferrous metals, conditions are generally more difficult in the case of processes like drilling, reaming and tapping (Fig. 6.11). Problems in dry machining include higher thermal loading of the tool, component and chip as well as the poor chip removal. Chips caught in or welded to the flute reduce the quality of the drill hole and can lead to tool damage. In tapping, compression, friction and adhesion phenomena lead to higher amounts of mechanical tool load. There are a number of drills, taps, fine boring and reaming tools available with special substrates, coating systems and tool geometries adjusted to the particular requirements of dry machining. Dry machining tools exhibit much better wear and performance properties than conventional wet machining tools.

Despite promising attempts to expand the field of application of dry machining and to make it more economical by finding appropriate tool geometries, coatings and cutting parameters, it is incontestable that a complete relinquishment of cutting fluids will not be possible for all machining tasks. Restrictions may derive from the method, material or required component precision.

Process substitution is a possible alternative. One example of this is the manufacture of internal threads by thread milling and combination drill taps. Interrupted cuts and the use of coated milling tools made of cemented carbide are favourable prerequisites for manufacturing threads by dry cutting, improving surface quality and even reducing manufacturing times [Kloc98].

Effects on the rim zone and form/dimension faults in the component represent further potential restrictions on dry machining processes. Since the component's quality is affected by the amount of heat that flows into the component, the process must be planned such that as little as possible heat enters the workpiece. Because they shorten the contact time between the tool and the workpiece, higher cutting speeds and larger feeds contribute just as much here as larger positive tool orthogonal rake angles, which reduce cutting work. This same is true for the reduction of friction, adhesion and wear by the use of coated tools. The distribution and number of cuts is very important. The operation should take place in one cut if possible. This demands components with volumes to be machined that are as small as possible as well as equal machining allowances. “Near-net-shape” parts, the final contours of which are frequently created with one cut, provide optimal conditions for this.

Manufacturing processes will in future no longer only be assessed from the standpoint of the improvement of performance but also with respect to ecological safety. In light of the problems associated with the use of cutting fluids, dry machining is surely the most effective approach in cutting technology to combining ecological objectives with economical advantages. Dry machining is feasible in numerous manufacturing methods. Many companies have recognized this and converted at least some components of their production to dry machining or minimum quantity lubrication. But it is also indisputable that cutting fluids will remain necessary for some machining tasks. For these processes therefore, we must look for alternative, environmentally friendly media that not only fulfil the functions of traditional cutting fluids but are also not potentially ecotoxic [Krie01, Kloc05].