Investigation of cooling and lubricating liquids

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Abstract

Considering increasing waste disposal problems in the area of cooling and lubricating liquids as well as their potential of health hazard and environmental endangering the question is to ask to what extend the customary way of cooling and lubrication in metalworking is still in keeping with the times. Several approaches to solve this problem seem to be suitable to guarantee a better human and environmental agreeableness as well as a smaller consumption. To make a reliable statement about the possibilities for the application of reducing strategies and their limits, fundamental knowledge about the process-changing characteristics of cooling and lubricating liquids in general is required. Concerning this, it is important to know more about the mechanism which enables the moistening of the tool's cutting edge with cooling lubricants in spite of, especially in case of turning, high pressure, high temperatures and opposite kinetics in the cutting area.

Keywords: *Production process, cooling lubricants, metal cutting*

The environmental awareness, which has been considerably grown in the last years, and the increasing waste disposal problems under the pressure of a more severe legislation, nowadays oblige more and more industrial firms to go into the questions of environmental compatibility of their production. Although each field is concerned with that problem, the key role falls to the production.

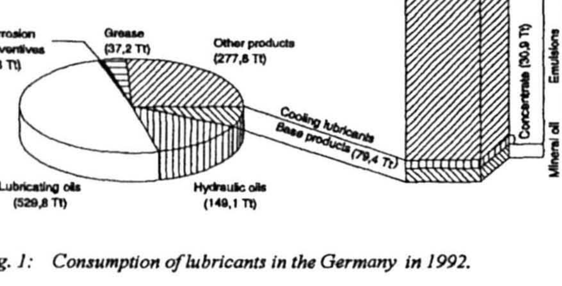

Fig. 1: Consumption of lubricants in the Germany in 1992.

In Germany, a total of 1.081.000 tons (t) of lubricants were consumed during the first 11 months of 1992. The share of cooling lubricants for metal working is about 79.000 t in the same period and is subdivided in non-water-soluble metal working oils and water-soluble concentrates (Fig.1). Regarding the mentioned consumption it has to be considered that only the oil quantities contained in the cooling lubricants are recorded. The problem of waste disposal in the field of cooling lubricants becomes clear when considering, that water-soluble cooling lubricants consist of only about 5% concentrate. From this results a total quantity of about 600.000 tons emulsion, which for the most part has to be disposed after use.

Because the waste disposal costs for waste oils, in consequence of stronger legal orders and growing consciousness of environmental problems, are growing permanently, the 'process material cooling lubricant' recently moved into the centre stage of interest more and more.

To reduce the costs, which are caused by the use of cooling lubricants, various ways of solution are already discussed, such as, e.g. the replacement of emulsion by non-watersoluble oils, an increasing application of dry-cutting and the specific composition of metal working oils and -concentrates.

By the support of Oel-Held Mineraloelwerk, Stuttgart, Index-Werke GmbH & Co. KG Hahn & Tessky, Esslingen, and Steidle GmbH, Langenfeld, a research team of the Institut für Werkzeugmaschinen of the University of Stuttgart is investigating technological, tool and workpiece relevant, characteristic parameters for the turning process.

The progressive development of cutting materials towards ever increasing wear resistance in connexion with the continual development of machine tools allows an ever higher metal cutting capacity. To be able to manufacture high quality workpieces with the cutting speeds and feeds following from that, there are high demands on the technological characteristics of cooling lubricants. The high temperatures during the cutting process complicate the keeping of exact dimensional tolerances. At the same time, a tapered shape of the workpiece is caused by a thermal extention of the tool. Such deviations can be largely avoided by the use of cooling lubricants.

In case of dry cutting, there is an intense temperature rise in the area of the tool's cutting edge and thus a softening of the material which leads to a reduction of the cutting forces. With use of cooling lubricants this effect is largely prevented by the strong cooling effect. On the other hand, the friction is strongly reduced by the lubricating characteristics of the cooling lubricant emulsion, so that the results concerning tool life and achieveable surface quality are superior to the dry cutting process.

Topic of the investigations was the influence of a cooling lubricant emulsion's oil concentration on the machining result exemplary in case of turning of roller bearing steel 100Cr6 with standard TiC/TiN-coated carbide indexable inserts. The achieved surface quality and the wear behaviour respectively the tool life behaviour of the tool's cutting edge were a main area of the experimental run.

In the experiments, there was on the one hand a variation of the oil concentration in the cooling lubricant emulsion to get a statement about the cooling respectively the lubricating effect in dependance on the oil share. On the other hand, the cutting speed was varied in the range between 50 m/min and 250 m/min to investigate the influence of the process temperature on the machining operation. The used cooling lubricant concentrate contained the components mineral oil, emulsifying agent combinations of carboxylic acid salts and boric acid compounds of primary alkanolamines, diester oils and sulphur additives as well as small quantities of a fungicide. It was mixed in a 5 respectively 10 per cent concentration. Additionally there were experiments by using water as coolant and without any cooling lubricant.

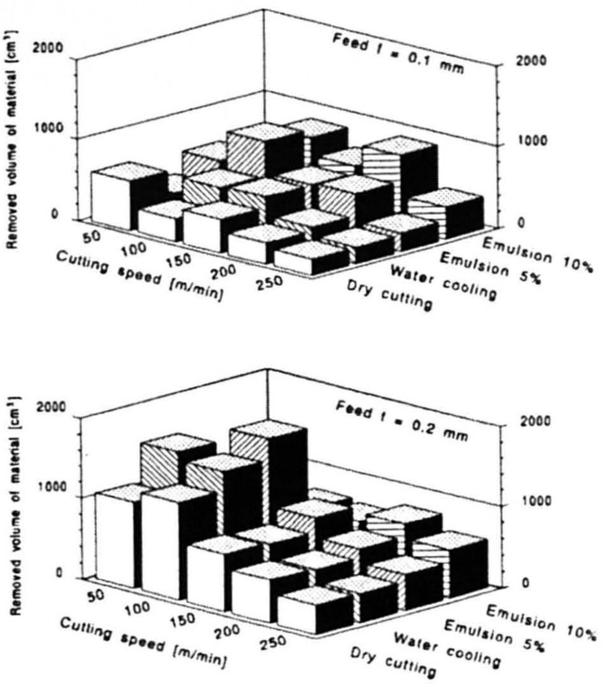

Fig. 2: Machined material volume until reaching a wear of cutting edge of 0,3 mm.

Figure 2 shows the removed volumes of material until reaching a wear of cutting edge of VB = 0,3 mm in reliance on the cooling lubricant and the cutting speed. It turned out that especially in case of very low cutting speeds, e.g. at v_c = 50 m/min, the tool life with cooling lubricant emulsion was shorter than under dry cutting conditions. The temperatures which are necessary for the response of certain additives can not be achieved at those low cutting speed and are even suppressed by the predominant cooling effect of the emulsion. The temperatures developping from dry cutting lead to a softening of the material so that lower cutting forces are necessary, which leads to reduced tool wear.

By contrast, the achieveable tool lifes in the area of higher cutting speeds can be clearly increased over the results of dry cutting by using cooling lubricants. This is illustrated by the course of the tool wear over the removed material shown in figure 3. While the wear of cutting edge increases permanently in case of dry cutting respectively water cooling and exceeds the label of VB = 0,3 mm already after a short time, using cooling lubricant emulsion ensues a quasi-stable phase, the so called working sharpness of the tool, with an only slightly increasing wear. Thus, the removeable material volumina until the reaching of the wear limit are clearly higher in this case. The temperatures, which are necessary for the response of the extrem-pressure additives (EP-additives) of the emulsion are reached. Those additives react with the highly active metal surface and constitute an efficient lubricating film.

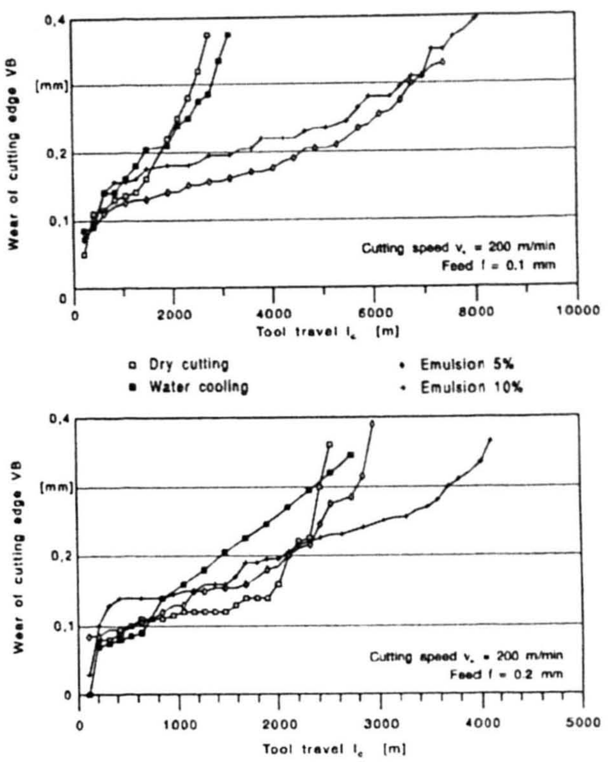

Fig. 3: Development of the flank wear depending on cutting speed, feed and cooling lubricant.

Especially in the area of higher cutting speeds, the values of the tool life travel, achieved by the use of cooling lubricant, lie partially noticeable above the values of dry cutting. With an increasing cutting speed the maximum of the removed material volume until the reaching of a flank wear mark of 0,3 mm shifts towards higher oil concentrations.Thus, the values of tool life at a cutting speed of v_c = 200 m/min reach a maximum with an oil concentration of 10%. Compared with dry cutting an about 200% higher material volume can be cut by the use of a 10 per cent cooling lubricant emulsion which corresponds to a nearly triple tool life.

Concerning the surface quality dry cutting shows slight advantages compared with cutting with cooling lubricant especially in the area of low cutting speed. But these advantages decrease with increasing cutting speeds. The worst surfaces resulted from the use of water as a coolant. At v_c = 100 m/min the surface roughness with R_z = 16,4 µm lies about 12,2 µm above the value of dry cutting. The surface quality related results of the two emulsions have been slightly worse, 2 and 3 µm, than those of dry cutting.

The surface values of the four experimental runs approach with increasing cutting speed. In case of dry machining, however, the severe temperature rise of the workpiece has to be considered, which, especially in case of smaller workpieces, strongly affects the accuracy of dimensions and shape. Judging the annealing colours occuring on the finished workpieces, it can be assumed, that the test specimen became heated up to 350°C and more during machining. As a result, an acceptable dimensional accuracy may no longer be guaranteed. In the specific case the deviations of the diameter amounted up to 5%.

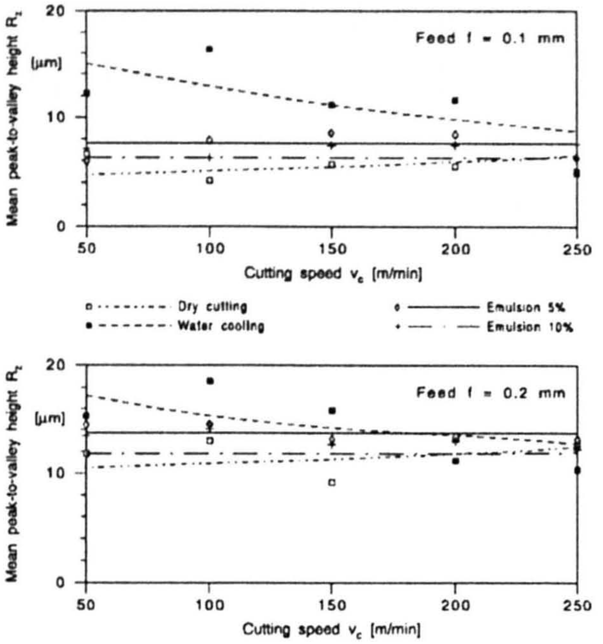

Fig. 4: Surface quality of the work pieces depending on cutting speed, feed and cooling lubricant.

The analysis of the test results allows the conclusion, that in the sector of metal cutting, the use of cooling lubricant emulsion is still economically justifiable and technologically necessary. The experiments showed, that, according to cutting speed and feed, the tool life depends on the oil concentration in the cooling lubricant. Across the whole analyzed range of cutting speeds a constant surface quality is achieved. Water as cooling liquid does not seem to be suitable because a satisfying tool life is not to be achieved apart from cutting at low cutting speeds. The quality of the machined surfaces contradicts the use of water as well as the highly corrosive effect on workpiece and machine tool.

Dry machining seems to be an interesting procedure for the pre-working of workpieces with relatively low cutting speeds and high feed rates. The large chipsections usual in this case allow an improved carrying-off heat and high time-cutting volumina. The dimensional and form accuracy is only of secondary importance because of the subsequent finish-machining.

Looking at the increasing costs for waste disposal, it will be to consider whether dry machining can be applied in such domains where up to now only insignificant tool life advantages can be achieved by the use of cooling lubricant emulsions. Considering all influences and realizing a comprehensive economics examination, it will turn out that even with a slightly lower tool life but without the arising waste disposal costs, it is possible to produce in a more economic way, especially in case of premachining, with dry machining.

The often euphorically demanded total renouncement of cooling lubricants, however, seems not to be realistic after the evaluation of the experimental results. On the contrary the future use of cooling lubricants will be economically justifiable and technologically necessary in many fields of metal cutting. An optimized use of cooling lubricants should, however, be aimed at. One possibility therefor is the use of non water-soluble oils as cooling lubricant. Present research activities at the Institute for Machine Tools (IfW) dealing with this subject are expected to show good results concerning tool life and work surface, while the durability of the cooling lubricant is nearly unlimited. Merely losses caused from drag-out and evaporation have to be compensated. Further possibilities for the reduction of cooling lubricants are: The use of environmentally compatible and non-noxious base materials and additives. Those components have to fulfill the following demands to be classified as environmentally compatible:

- The cooling lubricant should be environmetally neutral during its production. That means low energy consumption, no waste products and emissions.
- Cooling lubricant should be produced from regenerative, mainly native raw materials. As a result, valuable ressources could be spared.
- Cooling lubricant has to be physiologically safe. It must not have a toxic, carcinogenic (cancer-causing), nor any other health-impairing effect.
- Cooling lubricant has to be ecologically compatible, should be unmixable with water - a special problem of emulsions - and should not lead to water pollution.
- After use, residues of cooling lubricants should be easily biodegradable and should, at the same time, not generate any noxious degradation products.
- Cooling lubricants should distinguish themselves by simple recycling-possibilities and therefor cause no waste disposal problems.

A third possibility to minimize the cooling lubricants problem is the reduction of the used quantity of cooling lubricants with a minimum quantity cooling lubrication.

To be able to make a reliable statement about the ranges of application and the limits of these reduction strategies, a fundamental knowledge about the process-influencing characteristics of the cooling lubricant is essential. To this counts above all the investigation of the mechanism, which enables a moistening of the cutting edge with cooling lubricant, despite of high pressures and temperatures, and despite of opposed kinematics in the cutting area. For this purpose, a test stand has been designed and built in the Institute for Machine Tools (IfW). By using the so-called 'Off-Shore-Technology' it allows a reliable and defined moistening of the cutting edge with cooling lubricant during the whole turning process.

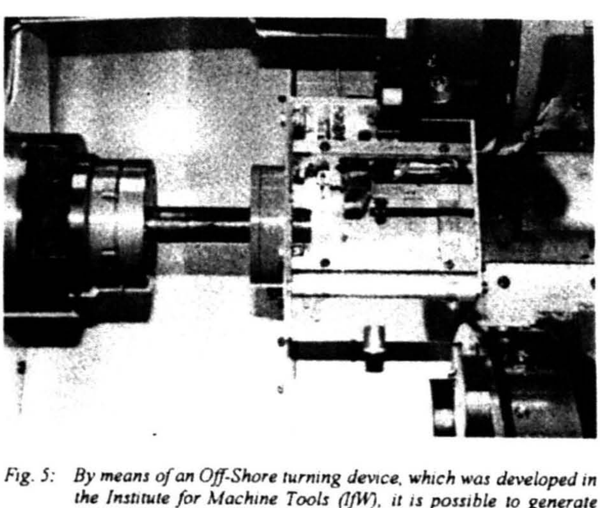

Fig. 5: By means of an Off-Shore turning device, which was developed in the Institute for Machine Tools (IfW), it is possible to generate defined moistening conditions at the tool edge.

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