

**Technical note**

# **INFLUENCE OF COOLING LUBRICANTS ON THE SURFACE ROUGHNESS AND ENERGY EFFICIENCY OF THE CUTTING MACHINE TOOLS**

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The Technical University of Liberec and Brandenburg University of Technology Cottbus-Senftenberg investigated the influence of cooling lubricants on the surface roughness and energy efficiency of cutting machine tools. After summarizing the achieved experimental results, the authors conclude that cooling lubricants extensively influence the cutting temperature, cutting forces and energy consumption. Also, it is recognizable that cooling lubricants affect the cutting tools lifetime and the workpiece surface quality as well. Furthermore, costs of these cooling lubricants and the related environmental burden need to be considered. A current trend is to reduce the amount of lubricants that are used, e.g., when the Minimum Quantity Lubrication (MQL) technique is applied. The lubricant or process liquid is thereby transported by the compressed air in the form of an aerosol to the contact area between the tool and workpiece. The cutting process was monitored during testing by the three following techniques: lubricant-free cutting, cutting with the use of a lubricant with the MQL technique, and only utilizing finish-turning and finish-face milling. The research allowed the authors to monitor the cutting power and mark the achieved surface quality in relation to the electrical power consumption of the cutting machine. In conclusions, the coherence between energy efficiency of the cutting machine and the workpiece surface quality regarding the used cooling lubricant is described.

**Key words:** machining, turning, milling, process fluids, minimum quantity lubrication.

## **1. Introduction**

At the preparation of a cutting process, the choice of an adequate cooling lubricant and the way of its supplying to the contact area between the machining tool and workpiece is important.

Because of their cooling, lubricating and cleaning effects, these process liquids affect substantially the working process, thus also the results. Besides these essential properties, process liquids need to highly perform subsidiary properties that regard, e.g., the environmental and biological compatibility as well as properties concerning compatibility with machine itself. Moreover, purchase costs and waste disposal has to be considered in this context. [1, 6, 9, 15]

Especially the following physical and chemical properties of the cooling lubricants are very important:

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- easy applicability,
- high operational stability,
- minimal foam generation,
- good filterability and ability of sedimentation,
- good wettability,
- favourable cleaning and transport properties,
- passivity concerning painted surfaces and sealants,
- conservation of properties concerning fire-protection during storage and usage. [2, 11].

Not only to adjust but also to optimize the behaviour and properties of a process liquid, it can be treated with several additives. Unfortunately, these additives can decrease the environmental compatibility of the process liquid. [8, 10] Less negative effects are thereby achieved through the use of plant oil-based additives due to their more favourable biodegradability. On the contrary, in the case of dry processing, no process liquids are used. As a compromise to these both extremes, the Minimum Quantity Lubrication (MQL) technique can be used where only a minimum of process liquid is added during the process. Hence, environmental compatibility and production costs are affected positively. [3, 4, 7, 14]

## 2. Performed experiments

The steel type C45+N was used during the turning and milling experiments with the following supplied process lubricants:

- Paramo SK 300 (aqueous solution),
- Microcool 378+ (half-synthetic emulsion),
- Accu-Lube LB 2000 (oil-air mixture).

As a part of the experiment preparations, the process liquids were prepared out of the concentrate according to the recommended parameters and were counterchecked just by the use of a refractometer. The cutting process parameters were chosen in order to comply with those of the general finish-machining. Each monitoring of the processes during turning and milling was performed three times under constant conditions. Subsequently, the achieved results were analysed statistically. To ensure that the measurements are not affected by the increasing tool wearing, a new tool was used for each series of measurements. [12, 13] For the turning process investigation, the universal turning machine of type SU 50 with the tool holder Iscar WNMG 432-NR IC 9025 and indexable insert Iscar MWLNR 2525-08W with the Wipe-cutting edge geometry was used.

The tool holder with a coolant supply insert MICRONA with its nozzles close to the cutting area enabled the application of the process liquid in the form of an oil-air mixture (MQL). The chosen turning parameters were as follows:

- Depth of cut  $a_p = 0.4 \text{ mm}$
- Cutting speed  $v_c = 176 \text{ m/min}$
- Feed rate  $f = 0.05 \text{ mm/rev}$

The process of milling was performed on the machine of type FNG 32 (TOS Olomouc s.r.o). The used tool Pramet SPEW 1204ADSN features five edges with the indexable inserts. The important cutting parameters were as follows:

- Depth of cut  $a_p = 1.0 \text{ mm}$
- Cutting speed  $v_c = 135.7 \text{ m/min}$
- Feed rate  $f = 1.5 \text{ mm/rev}$

The evaluation of the used cooling lubricant was made through the measured impact on the whole cutting process, cutting force  $F_c$  and cutting power  $P_c$ . The cutting force  $F_c$  was measured by the piezoelectric dynamometer KISTLER 9265 B and charge amplifier 5019 B. The cutting power was finally calculated from the cutting forces and cutting speeds. In order to evaluate the processed workpiece surface quality, the appropriate measurement of the surface roughness  $Ra$  was performed on five different areas for each workpiece. [5] Roughness was measured with the device Mitutoyo SV-2000N2 SurfTest and evaluated with the program SURFPAK. The following processing of the measured experimental data was performed by the use of program LabVIEW 6.1.

### 3. Evaluation of the experimental data: Cooling lubricants affecting process properties

The results of the cutting forces  $F_c$  in dependence on the specific process media for the turning and milling techniques under the process parameters described above are shown in the following Fig.1.

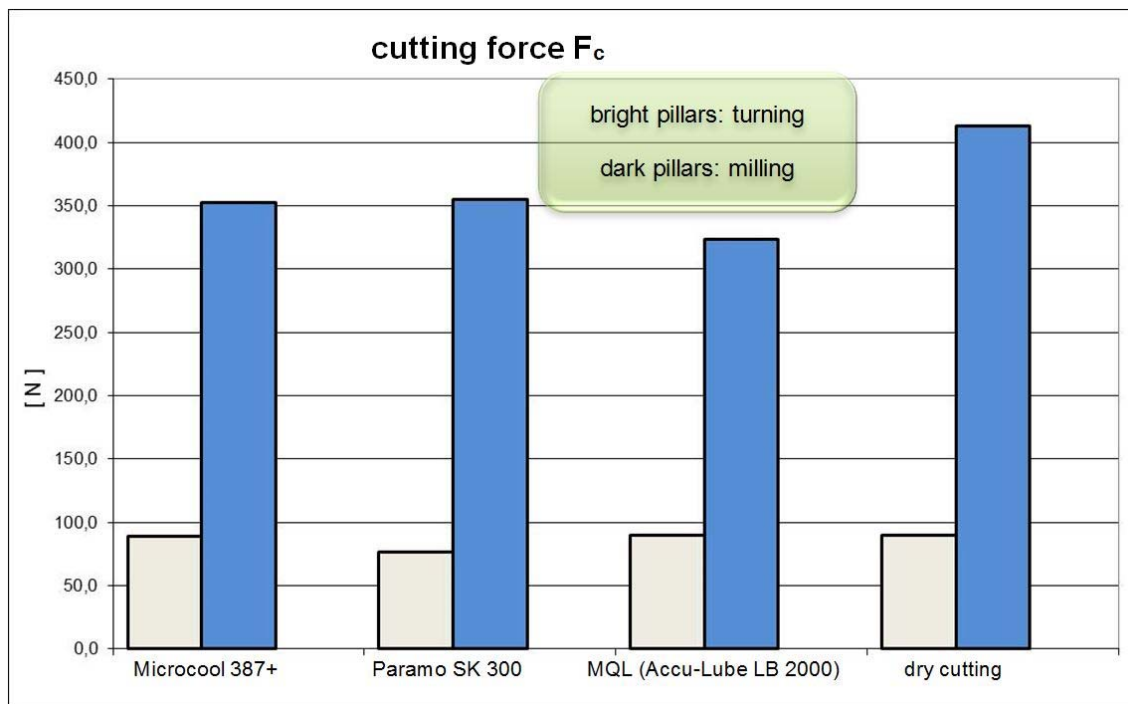


Fig.1. Mean values of cutting forces  $F_c$ .

For turning (bright columns), measured cutting forces are within the range of 77 N and 90 N. The best results and hence the lowest cutting forces were achieved with the utilization of the process liquid Paramo SK 300 as an aqueous solution. In contrast to this, the highest cutting force in the case of turning was achieved when the cutting oil Accu-Lube LB 2000 was used as the process liquid.

In the case of milling (dark columns), measured cutting forces were between 323 N and 413 N. While the lowest values were achieved with the Accu-Lube LB 2000-based oil-air mixture, the highest cutting forces occurred during lubricant-free processing or dry cutting.

Figure 2 depicts the relative results, based on the gathered experimental data for dry cutting taken as 100%-mark.

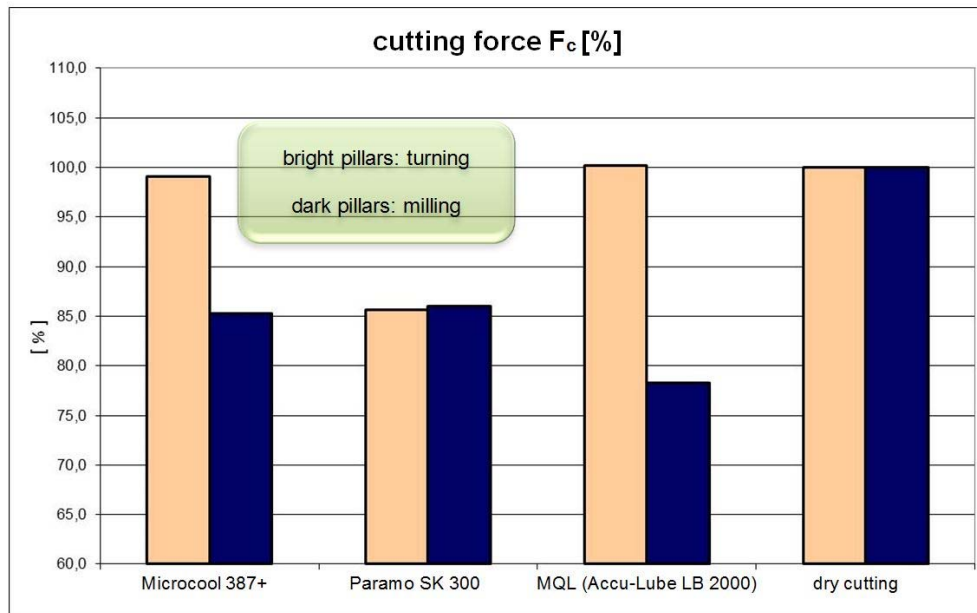


Fig.2. Percentual results of cutting forces  $F_c$ , related to dry cutting (100%).

In comparison to the overall values of the dry-cutting process, the usage of the process liquid Paramo SK 300 reduces the cutting forces approx. by 14%. In contrast to that, the application of the oil-air mixture Accu-Lube LB 2000 raises the cutting forces slightly over the 100%-mark.

For milling, the usage of the cooling lubricant Microcool 378+ and Paramo SK 300 revealed a reduction of cutting forces approx. by 15%. Moreover, the application of the cooling lubricant Accu-Lube LB 200 resulted in 22% reduction of the cutting forces during the experiment.

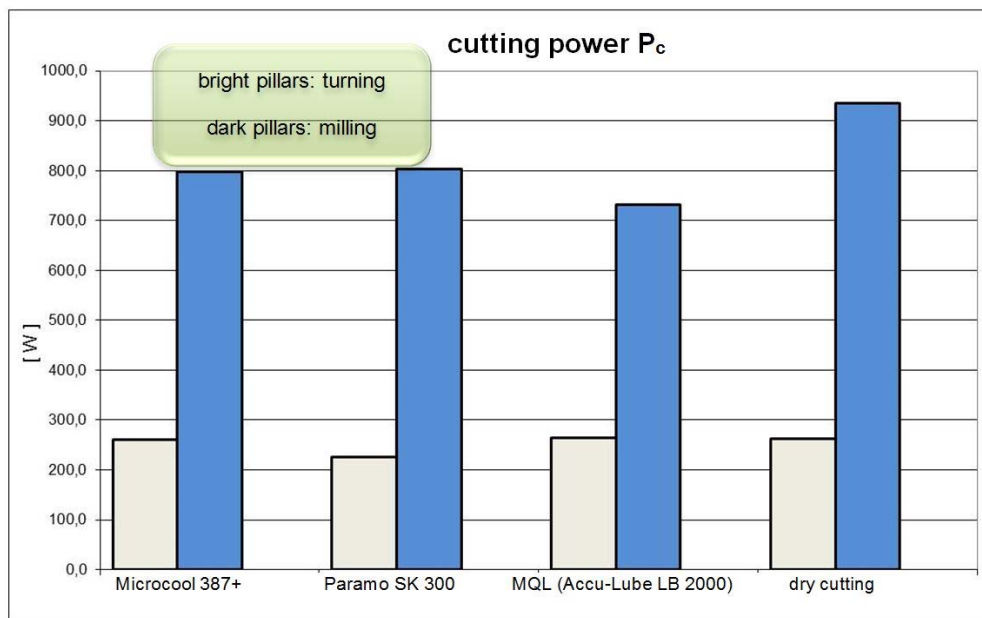


Fig.3. Mean values of cutting powers  $P_c$ .

Figures 3 and 4 illustrate another important parameter of the cutting process - resulting cutting power  $P_c$ . In these diagrams, bright columns are always related to the turning process, while dark columns are representing the milling process.

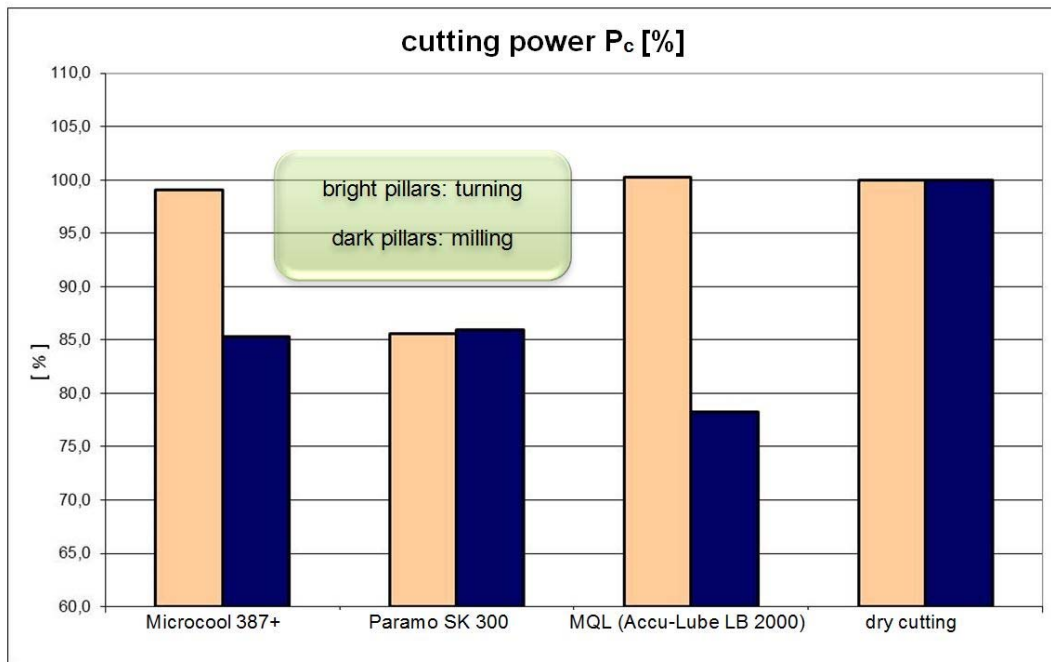


Fig.4. Percentual results of cutting powers  $P_c$ , related to dry cutting (100%).

Overall measured values of cutting power for finish-turning were between 225 W and 260 W, during finish-face-milling within the range of 731 W and 935 W. The cutting power is thereby proportional to the cutting forces.

Figure 5 depicts the dependence of the surface roughness Ra on the choice of cooling lubricant.

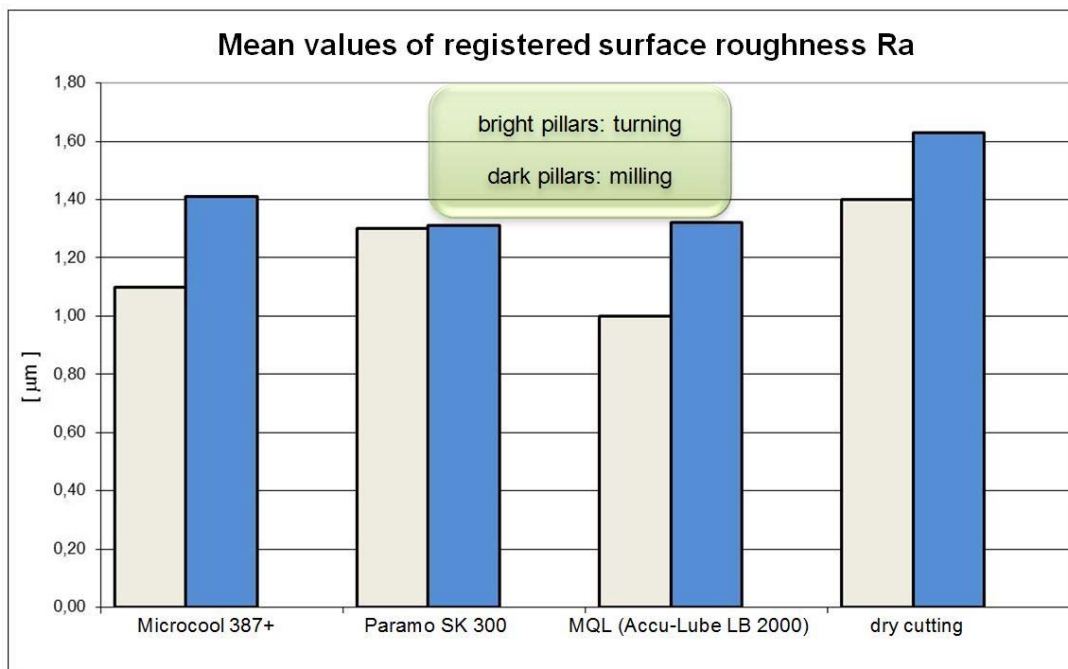


Fig.5. Mean values of registered surface roughness Ra.

In light of the measured surface roughness, the difference between the turning and milling process is very small. Turning with the use of Accu-Lube LB 2000 resulted in surface roughness values between  $1.0 \mu\text{m}$  and  $1.4 \mu\text{m}$ . Similarly good results were achieved under the usage of Microcool 387+. In contrast to that, the worst surface roughness value was measured after dry-cutting of the workpiece.

Finish-face milled workpieces revealed surface roughness values between  $1.3 \mu\text{m}$  and  $1.6 \mu\text{m}$ . The best results were achieved with the usage of Paramo SK 300 and Accu-Lube LB 2000. Again, the worst surface roughness values were measured after the dry-cutting process.

Figure 6 shows the final results of the surface roughness  $R_a$  which are again related to the dry-cutting process that is taken as the 100 %-mark.

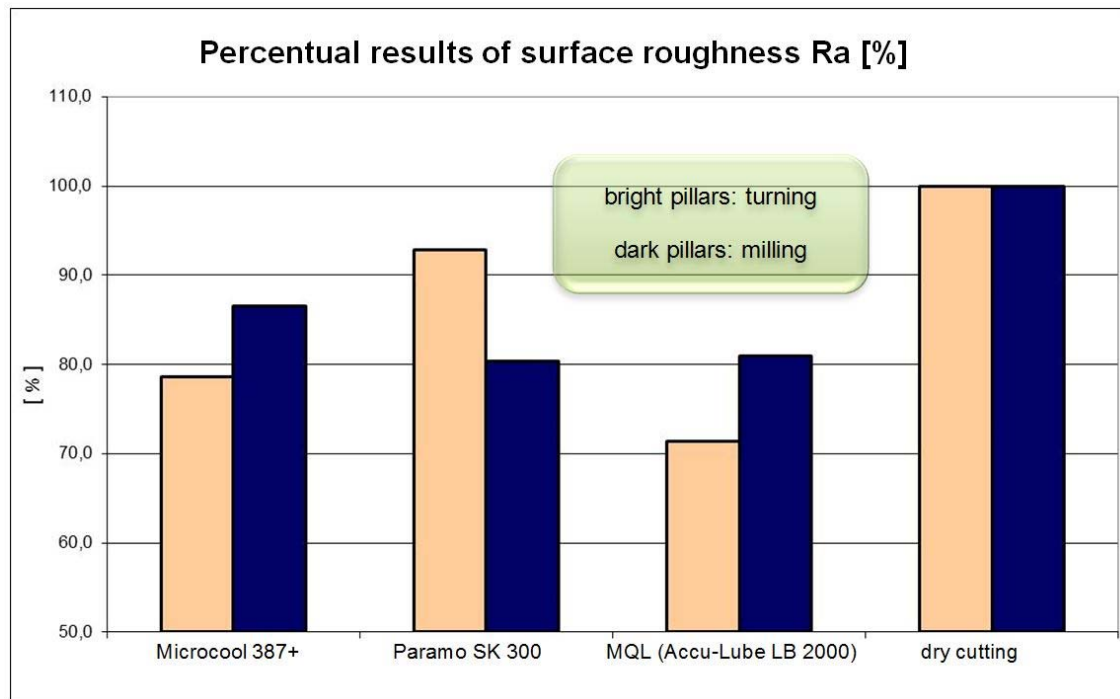


Fig.6. Percentual results of surface roughness  $R_a$  (mean values), related to dry cutting (100%).

As shown, the surface roughness decreases approx. by 29 % in the case of applying the MQL-technology during turning. As the process liquid Microcool 387+ is used, surface roughness is at least by 21 % smaller, while the usage of Paramo SK 300 as the cooling lubricant reveals only 7 % optimized values. Finish-face milling with the cooling lubricant Paramo SK 300 or Accu-Lube LB 2000 also improved the surface roughness - approx. by 20 %. On the other hand, it was reduced only by 13% compared to dry-cutting with the application of Microcool 387+.

#### 4. Studies concerning the energy efficiency during machining

Studies concerning the energy efficiency during machining were carried out during the turning process on the turning machine Harrison M250. Investigations were made during the longitudinal turning of structural steel S235 and Q&T steel C45E with different process parameters. Thus different values of the feed rates, cutting speeds, tool cutting edge radius and finally depths of cut were used as process variables. Furthermore, indexable inserts with the different tool nose radii ( $0.2 \text{ mm}$ ,  $0.4 \text{ mm}$ ) were attached (see Fig.7) During every measurement, the specific cutting force and the effective power of the turning machine were

measured. This made is possible to calculate corresponding cutting powers and efficiency. The achieved results for the dry-cutting are shown and shortly explained below.

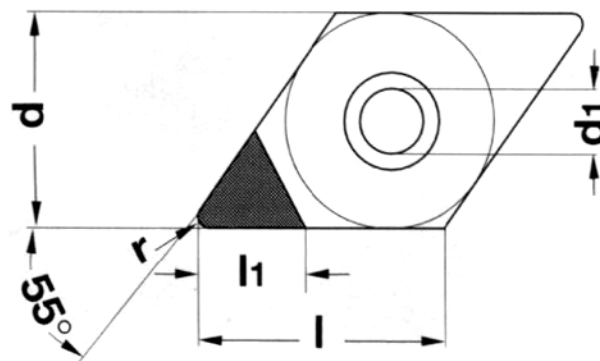


Fig.7. Indexable insert with the tool nose radius  $r$  (Corner radius  $r$ ).

Figure 8 illustrates the influence of the different tool cutting edge angles on the efficiency.

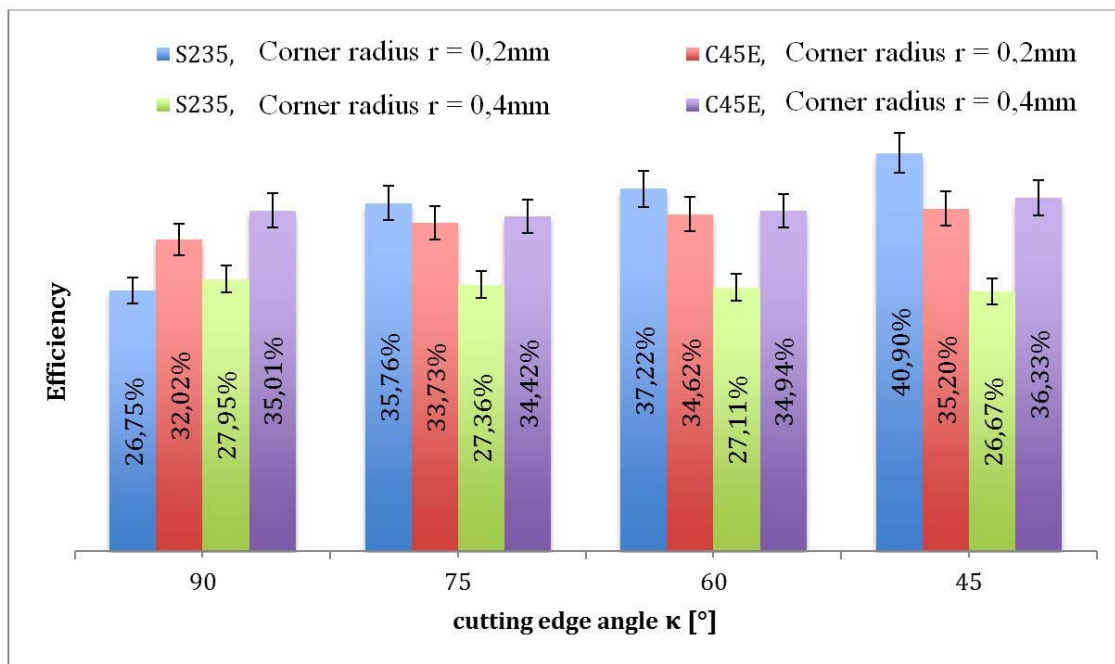


Fig.8. Efficiency values for different tool cutting edge angles.

It is important to note that during this series of experiments, the whole turning process efficiency of both tested materials slightly increases by decreasing both the tool cutting edge angle and tool node radius. In comparison to this, efficiency is not changing for a tool nose radius of  $0.4\text{ mm}$ .

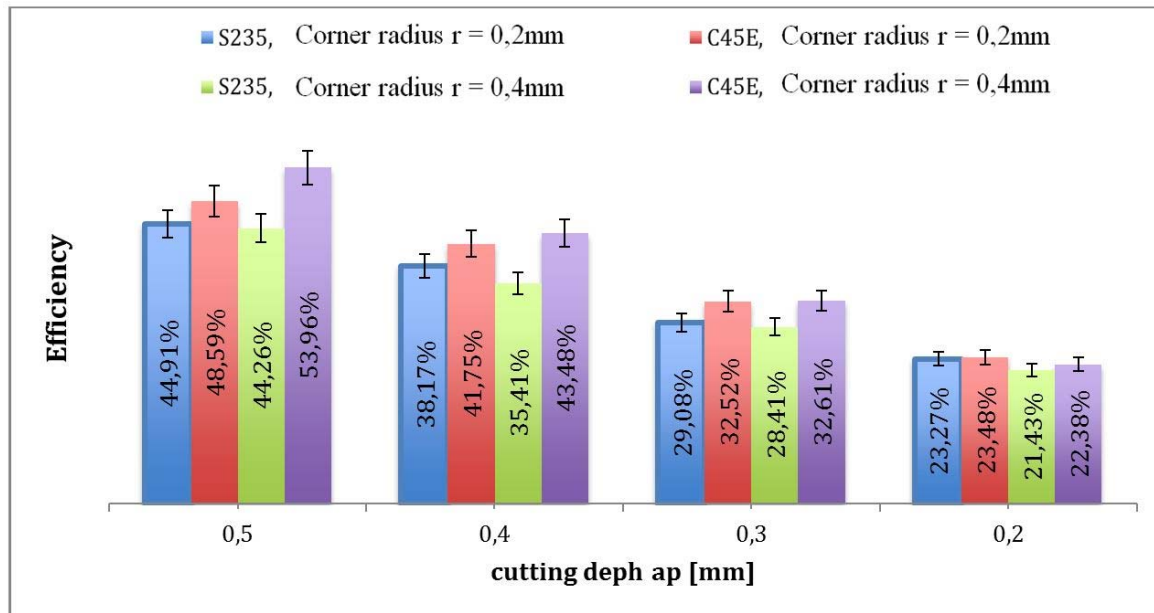


Fig.9. Efficiency values for varying cutting depth.

Figure 8 illustrates the efficiency of the whole process regarding the different values of the depth of cut. It is evident that the lower depth of cut, the lower the efficiency. As the machine is driven toward its power maximum, it reaches the maximal efficiency between 44% and 54% at depth of cut  $a_p = 0.5\text{ mm}$ .

Regarding the low nominal power of the turning machine, a longer lasting turning process cannot be performed for the main drive engine as it can cause damage to the electrical motor.

Comparable results were achieved for the experimental series for different feed rates and cutting speeds. Also here the efficiency increases as the higher cutting forces are achieved.

Error indicators (as standard deviations) approx. of 5% are also shown in the diagrams to take into account the variation of the engine and power supply.

## 5. Conclusions

The best results concerning the turning process including cutting forces and cutting powers were achieved with the use of the process fluid Paramo SK 300. Additionally, it was possible to decrease the surface roughness by using this cooling lubricant. The smallest surface roughness values were achieved by applying the MQL technique. Based upon these results, it can be stated that the use of MQL did not result in an evident reduction of the cutting forces or powers. As the results are within the range of dry-cutting, it is not possible to reduce process forces by supplying the process with Microcool 387+. Only the surface roughness was affected positively.

The application of the MQL-technology to finish-face milling reveals especially interesting results – i.e. a surface roughness reduction by 29%. Supplying Accu-Lube LB 2000 in an aerosol form to the contact area resulted clearly in the best values for cutting forces and cutting powers, as they were reduced up to by 22%. Additionally, the achieved surface roughness can be marked as very good. As far as the surface roughness is concerned, only the use of Paramo SK 300 revealed not very good quality of this parameter. The results of cutting forces and powers, for the chosen process media Paramo SK 300 and Microcool 387+ vary within a comparable range and revealed a reduction of these process parameters approx. by 15%.

First results of the studies performed in Senftenberg have been already published. [16] Preliminarily, it can be stated that investigations about the influence of process liquids on the turning and milling technology lead to interesting results, as cooling lubricants are affecting the turning and milling process



itself, as well the surface roughness. Experiments and their results confirm that applying the MQL technology influences positively the overall results in terms of quality, economics and ecology aspects.

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