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CUTTING FLUIDS FOR ENVIRONMENTALLY CLEAN MANUFACTURING

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1. INTRODUCTION

When considering environmental issues in machining, one of most fundamental concerns is the use of cutting fluids. They have a direct influence on the environment and in recent times are being questioned in the light of ecological and economic manufacture. Expertise in relation of cutting fluids is currently divided amongst the disciplines: chemistry, process technology, manufacturing technology, environmental conservation, medicine and tribology.

For manufacturing organisations that perform machining or cutting operations, cutting fluids represent an issue of growing interest owning to environmental, health, economic and safety concerns. These fluids include such chemical constituents as hydrocarbons, sulphur, phosphorus, chlorine, surfactants/emulsifiers, and biocides. The handling of used cutting fluids presents a number of environmental issues. Fluid splashing, spillage and improper disposal can contaminate lakes, rivers and ground water sources. Pre treatment and treatment of cutting fluids serves to reduce the environmentally damaging influence of the fluid, but not completely eliminate the potential hazard [1,7].

Looses of cutting fluids from the manufacturing system occur through:

- Vaporisation
- Loss with chips and workpiece as they leave the machine tool
- Loss with machine components such as handling/ manipulation devices
- Vacuum and air pressure systems and
- Droplet formation and ensuring leakage

Leakage of fluid is a critical factor contributing both loss and in some cases has a negative influence on the hydraulic systems of the machine tool. Wet and dirty workpieces, chips and particles leave the machine tool and enter the cleaning and drying system. Taking into account that up to 30% of the annual total cutting fluid consumption can be lost through removal from the system by the above means, it becomes clear that effective methods to combat such losses are being continually sought. The following points have to be observed in consideration of the question of cutting fluids for environmentally clean manufacturing

- The constituents of the cutting fluid must not have negative effects on the health of the production worker or on the environment.
- During their use cutting fluids should not produce contaminants nor have negative effects on machine tool components or seals.
- The cutting zone should not be flooded but rather cooling and lubrication should take place in a defined manner, thereby minimising the volume of fluid necessary, for example internal supply to within the tooling and specifically designed nozzles for external supply.
- Continuous monitoring of cutting fluid and the machine tool environment with online sensors is desirable.
- Through separate care and maintenance of cutting fluids, the total amount of oil and water required for emulsion can be reduced leading to cost savings.

Coolant and lubricants are in the recent years increasingly recognised as undesirable factors in metal cutting. For both economical and ecological reasons as well as due the growing extend of legislation.

The problem of cutting fluid disposal in manufacturing is the most important aspects in relation to the (plant) internal and external environmental protection and one objective of research work is the improvement of the life of cutting fluid by the fluid manufacturers and by high quality maintenance and monitoring.

Surveys carried out in German Automotive industry show that workpiece related manufacturing costs incurred with the deployment of cutting fluid cost range from 7 to 17%. As compared to this, tooling costs can account for approximately 2 to 4% . The vide range of within which cutting fluid costs fall is due to varying boundary conditions of manufacturing.

To cool the complete machining system (machine tool, workpiece and cutting tool) it can be used:

- Conventional internal coolant with emulsion
- Cutting internal coolant with oil 80 bars
- Near dry technique - beam sparkling
- Dry technique
- Cutting with native oil

2. PRINCIPLES OF DRY MACHINING

The introduction of dry cutting requires suitable measures to compensate for the primary function of fluid. This requires a trough understanding of complex interrelationships which link process, tool, part and machine tool. In dry machining, functions of cutting fluid must be submitted. For the cutting process, these functions are cooling, lubrication and chip disposal, and for the machine they include cooling and flushing.

The absence of cooling in dry machining leads to temperature increase the consequence of which can be higher wear, residual stress within the workpiece, dimensional and shape errors, influence oh fringe layers, chip melting and chip build up edge on tool and workpiece.

The absence of lubrication results in temperature increase due to increased friction, and the lack of separation between tool and chip leading to an increased tendency of adhesion can more easily cause chip build up edge on the tool.

The absence of the function of chip disposal by means of cutting fluid can cause chip build up on tool and workpiece, clogging of chip surface, and damage to surface already generated due to chips caught between cutting edge and workpiece and thus being cut again.

The absence of temperature-moderating effects on machine components can cause dimensional errors due to thermal variations of the machine.

The absence of flushing effects (moving chip to chip conveyors) causes heavier pollution of machine tool. Chip left lying can cause punctual heat-up of machine tool. Chip and dust left lying can also lead to clamping errors. Metal dust can damage the machine guide ways.

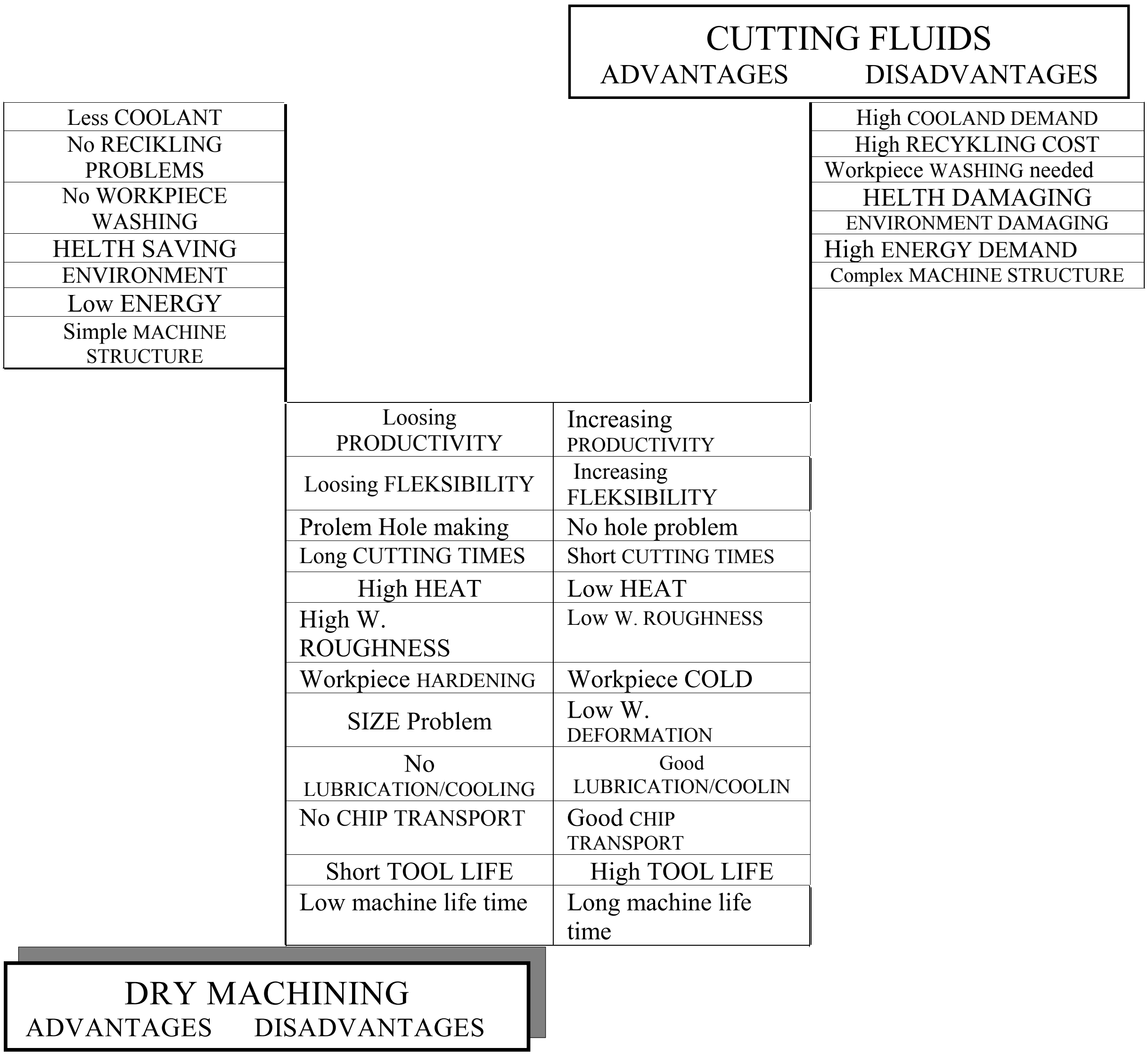

FIG. 1. COMPARISON BETWEEN DRY MACHINING AND MACHINING WITH CUTTING FLUID [7]

In some cases it is not possible to achieve dry cutting, e.g. where is strong adhesion between the cutting tool and the chip underside, where the tool wear is excessive under dry conditions or where thermal deformation of the workpiece cannot be controlled.

Tight dimensional and form tolerances may present a significant restriction to dry machining and call for special countermeasures. Examples where dry cutting, is applied include turning, milling and drilling (l/D < 3) of cast and steel materials. Tools for dry machining must incorporate specially designed features relating to the substrate, the coating and the geometry. Low friction in the tool workpiece contact zone and a high thermal resistance is required. A dry cutting process must be desired to minimise the amount of heat flowing into worpiece.

This may be achieved by minimising cutting forces and also by influencing the heat distribution. Cutting forces can be reduced by positive cutting edge geometries, which heat distribution towards the workpiece may be positively influenced by increasing the cutting speed.

3. DRY OR NEAR DRY MACHINING

A summary of the situation in relation to the use of dry machining and Near dry machining (NDM) for a range of materials: aluminium, steel and cast iron shows Table 1 [6]. In some cases, as for example in the milling and drilling of aluminium, very small quantities of fluid may be applied. Those processes in which the friction and adhesion play a dominant role generally require the usage of minimal quantities of fluid. Examples here include tread cutting and forming, fine drilling, and drilling of steels with l/D ratios < 3. Although somewhat misleading the term Minimum quantity lubrication (MQL) is commonly used.

MQL or Near dry machining (NDM) is defined as the dispensing of cutting fluids at optimal (generally very low) flow rates, tiny quantities of cutting fluid are sprayed to the cutting zone directly

TABLE 1. DRY OR NEAR DRY MACHINING

[redacted]	Aluminium		Steel		Cast iron
	Cast alloys	Wrought alloys	High alloy steel, bearing steels	Free cutting, quench and tempered steels	GG20 GGG70
Drilling	NDM	NDM	NDM	Dry/NDM	Dry/NDM
Reaming	NDM	NDM	NDM	NDM	NDM
Tapering	NDM	NDM	NDM	NDM	NDM
Treat forming	NDM	NDM	NDM	NDM	NDM
[redacted]				NDM	NDM
Milling	NDM/Dry	NDM	Dry	Dry	Dry
Turning	NDM/Dry	NDM/Dry	Dry	Dry	Dry
[redacted]			Dry	Dry	Dry
Sawing	NDM	NDM	NDM	NDM	NDM
[redacted]			NDM	NDM/Dry	Dry

In addition to environmental concerns associated with cutting fluids, several studies have shown that humans exposed to cutting fluids through dermal and inhalation pathways often develop health problems. Motivated by health problems related to cutting fluids mist inhalation, several recent efforts have focused on investigation the mechanisms associated with cutting fluids mist formation.

A final potential hazard associated with cutting fluid mist is safety related mist; with high oil concentration can be flammable. Finally, it should be noted that significant expenses associated with the purchase, maintenance, treatment, mist handling, recirculation, and disposal of cutting fluids represent yet additional motivation for manufacturing industry to carefully examine cutting fluid usage decisions [1,11].

Dry machining eliminates the environmental problems associated with cutting fluids. While there remain potential health hazards (dermal irritation and inhalation) and flammability issues from machining dust, these are far les of worry than for cutting fluid mist. NDM represents an intermediate alternative between copious fluid application and dry machining.

It attenuates many of the negative aspects associated with flood application and is still able to provide some of the process benefits not available with dry machining. NDM offers the following advantages: decreased use of metal working fluids, reduced costs as compared to flood application, reduced industrial hygiene hazard, opportunity to employ more benign fluids (e.g. vegetable oils) and improved process performance as compared to dry machining. Widespread use of NDM is still inhibited by concerns related to unknown costs, chip flushing problems potential flammability issues associated with airborne metal dust, and system reliability/repeatability.

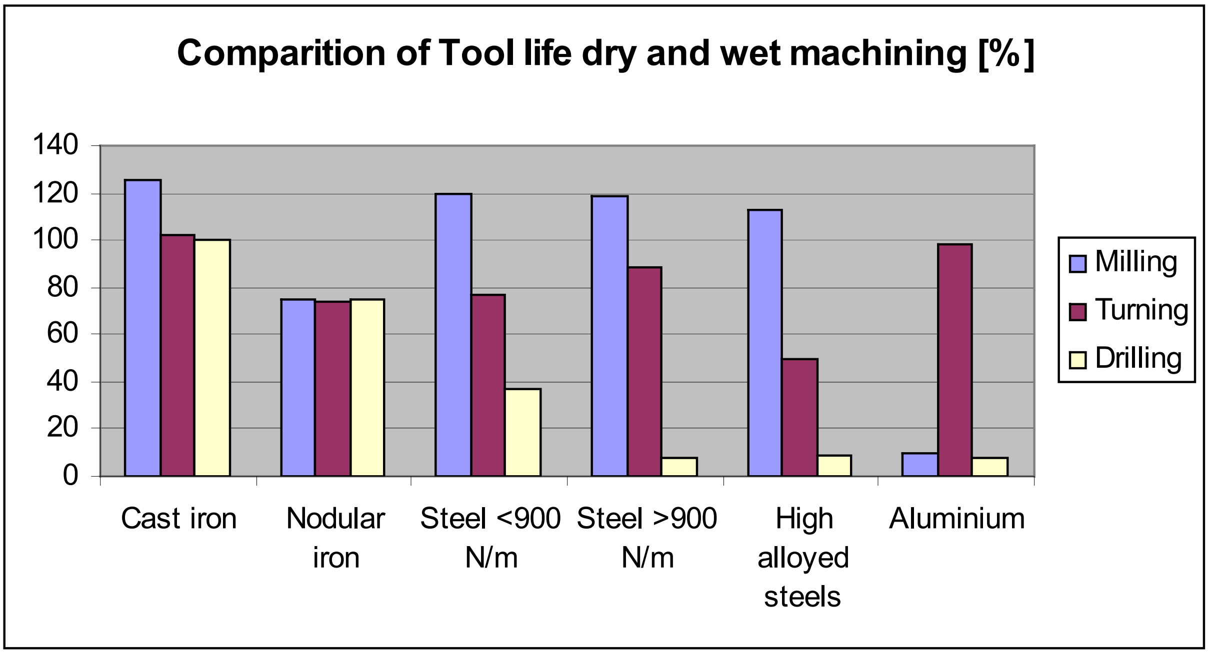

FIG. 2.COMPARITION BETWEEN TOOL LIVES OF DRY AND WET MACHINING IN [%]

4. MACHINING OF DIFFERENT MATERIALS

The dominant problems in machining and thus the requirements as to the process are specific for each combination of material and machining process. In machining steel, the major factor is high temperature, in machining cast iron or aluminium with high silicon content, is abrasive wear, and for aluminium is generally the high tendency of adhesion which can lead to build up edge on tool and workpiece. Also depending on the machining process, there are distinct difference between wet and dry machining process (Fig 2).

5. TOOLS AND CUTTING MATERIALS

The requirements as to the tools primarily results from need for good chip disposal which dry machining must be accomplished without the conveying action of the cutting fluid.

In dry machining, the process temperature is frequently higher than in machining with cutting fluid so that high-temperature wear resistance and hardness at elevated temperature are mayor factors. The hardness at elevated temperature of HSS is relatively low, so that hard metals, cermets and ceramic cutting materials should be primary in dry machining. However, the lowest bending strength of ceramic cutting tools materials prevents their universal use. For milling and drilling mixed ceramics are too brittle. If for certain machining applications it is indispensable to the use HSS, it should be provided with a high temperature - resistant coating. At high temperatures, TiAlN has higher hardness and is therefore better suited for dry machining than TiN.

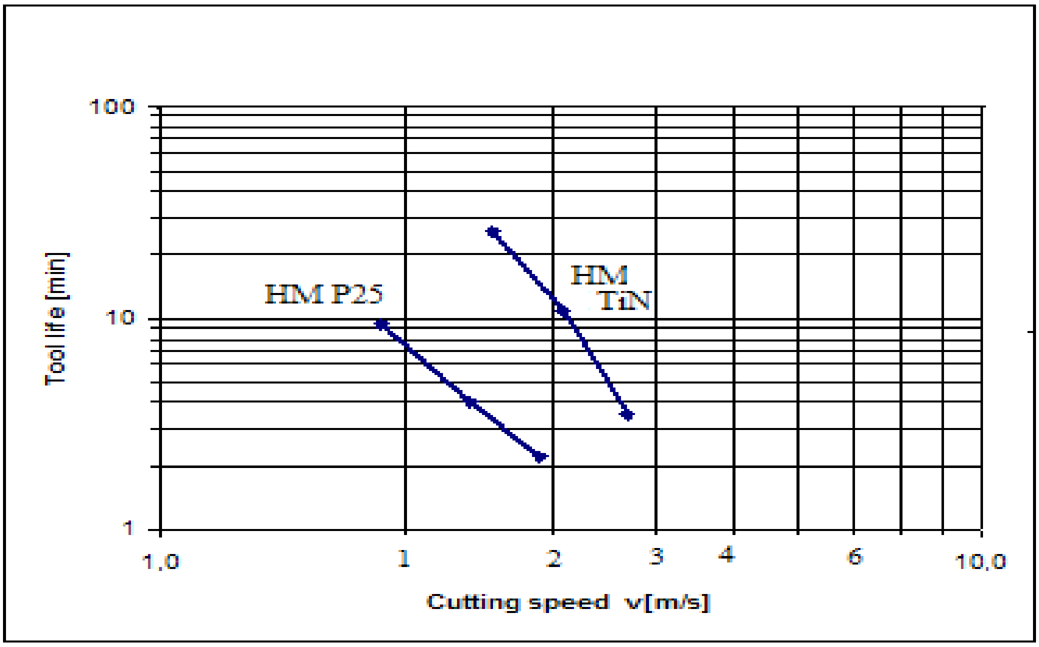

FIG. 3.TOOL LIFE WITH HM AND TIN COATING

For reduction of adhesion tendency and for decreasing the friction effect between chip and cutting tool, coatings such as CVD diamond and diamond-like carbon are available.

6. MILLING

In dry milling of steel with hard metal, longer tool life as compared with milling is frequently observed [9]. The reason for this is the substantial temperature load change action on the tool milling with cutting fluid. Coatings provide further improvement of tool life.

For aluminium wrought alloys, wear is relatively low, but the adhesion tendency is very strong. Adhesion can be substantially reduced, especially by application of minimal coolant systems.

In rough milling of globular cast iron containing spheroid graphite, tool life is greatly improve by using SiN ceramics and simultaneously increasing the cutting speed. Machining time is reduced to one fourth.

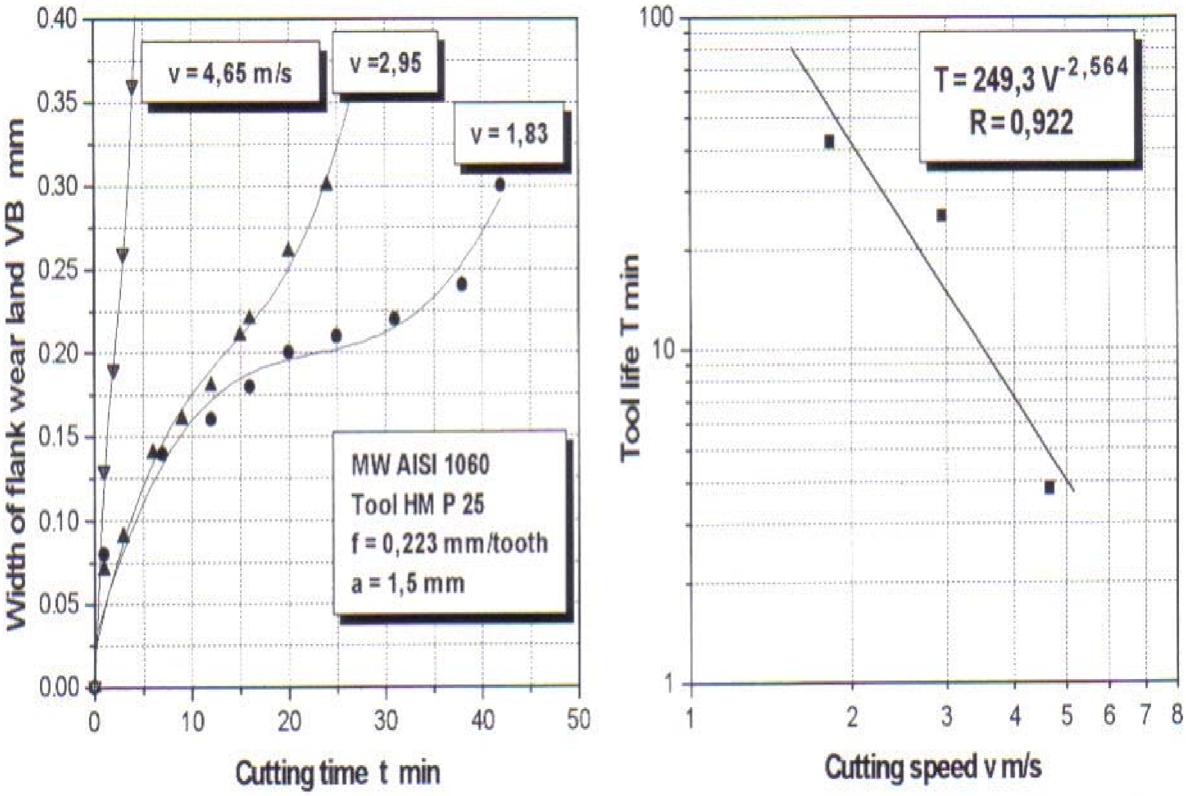

FIG. 4.TOOL WEARS AND TOOL LIFE DURING DRY MILLING [7]

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