Analysis of extent of environment load in alternative manufacturing procedures

JÁNOS KUNDRÁK, GYULA VARGA, ISTVÁN DESZPOTH
Institute of Manufacturing Science
University of Miskolc
3515 Miskolc Egyetemváros
HUNGARY
janos.kundrak@uni-miskolc.hu, gyulavarga@uni-miskolc.hu, istvan.deszpoth@uni-miskolc.hu,
http://www.ggyt.uni-miskolc.hu/index.php

Abstract: - The auxiliary materials for machining facilitate the quality and accuracy of component manufacturing as well as efficient material removal and increasing productivity. However, the auxiliary materials used (coolants and lubricants) burden our environment. In machining of the machine industry, volume of such materials needed to produce one part may not be large, but there are millions of parts, meaning that a detailed analysis is needed to minimize the quantity of the series as a whole. In this paper, a comparative analysis is performed based on coolants and lubricants used in hard machining processes where the cutting data are adjusted to give the same accuracy and quality to the component.

Key-Words: - Environment load, Material Removal Rate, hard turning, combined procedure, periodic surface, random surface

1 Introduction

Coolants and lubricants can help in both cooling and lubricating and in flushing-washing effects for cutting. As a consequence, most procedures use them in a significant quantity, which has led to a long-term increase in the use of coolants and lubricants. By using coolants and lubricants the tribological conditions improve at the interface of the workpiece and the tool, which contributes to increasing tool life, reducing tool wear, and making the heat dissipation more efficient, as the machining power needed in the cutting process is lower and the machined surface roughness is better [1]. These positive properties depend on the chemical composition of the coolants and lubricants used and mechanical properties of the applied cutting tool and workpiece. In addition, the applied range of cutting parameters also affects the choice of coolants and lubricants and the selection of the method of the cooling lubrication. Initiatives to reduce environmental damage have also caused a change in attitude in the field of machining. In addition to profit, the environmental load analysis is part of technological planning, but there is still a significant environmental load impact of the auxiliary materials used. Pusavec et al. [2] analyzed the machining processes and emphasized that sustainable production can be obtained by, for example, reducing the consumption of electricity, increasing tool life and improving the surface texture of the workpiece. Environmental load as a concept is being increasingly used in the wider sense as time passes. According to Mashhadi and Behdad [3], the interconnection of intelligent infrastructures is drastically increasing, which exponentially increases the environmental load.

The importance of the topic is shown by the fact that analyses related to environmental load are also present in connection to Industry 4.0. Jabbour et al. [4] examine the question of whether Industry 4.0 can revolutionize environmentally sustainable manufacturing. In their study, they analyze the potential of integration of Industry 4.0 objectives and of environmentally sustainable manufacturing. The synergy between Industry 4.0 and environmentally sustainable production is considered to be the basis for eleven critical success factors (Fig.1). These are: P1: Management leadership; P2: Readiness for organizational change; P3: Top management commitment; P4: Strategic alignment; P5: Training and capacity building; P6: Empowerment; P7: Teamwork and implementation; P8: Organizational culture; P9: Key role of communication; P10: Project management; P11: National culture and regional differences. Their work is aimed at examining the challenges and opportunities that these factors may have in this process.

Tanabe [5] proposes an analysis of the “dual ECO model” and environmentally friendly technologies as an alternative to current manufacturing methods. The model consists of two parts, one of which is "Ecology" (the interaction between the environment and humans), the other is "Economy" (the profit).

Trstenjak and Cosic [6] deal with process design in an Industry 4.0 environment. They draw attention to the harmful effects on people of new, rapidly changing working environments, such as radiation of computer monitors and displays of instruments, which are dangerous to the workers who are in front of them.

We narrow down our examination to production processes and within this to machining processes. It is essential to examine the environmental loads that are changing by the modernizing of procedures and the emergence of new ones, and to take into account their impact in connection with the technical, economic and environmental investigation of lubrication/cooling systems used in machining processes. According to Benedicto et al. [7], the global demand for lubricants in 2005 was 39.4 million tons and is expected to reach 43.9 million tons by 2022 [8].

Related to their applications, the most commonly used lubricants in the industrial lubricant market are gear oils, hydraulic oils and engine oils.

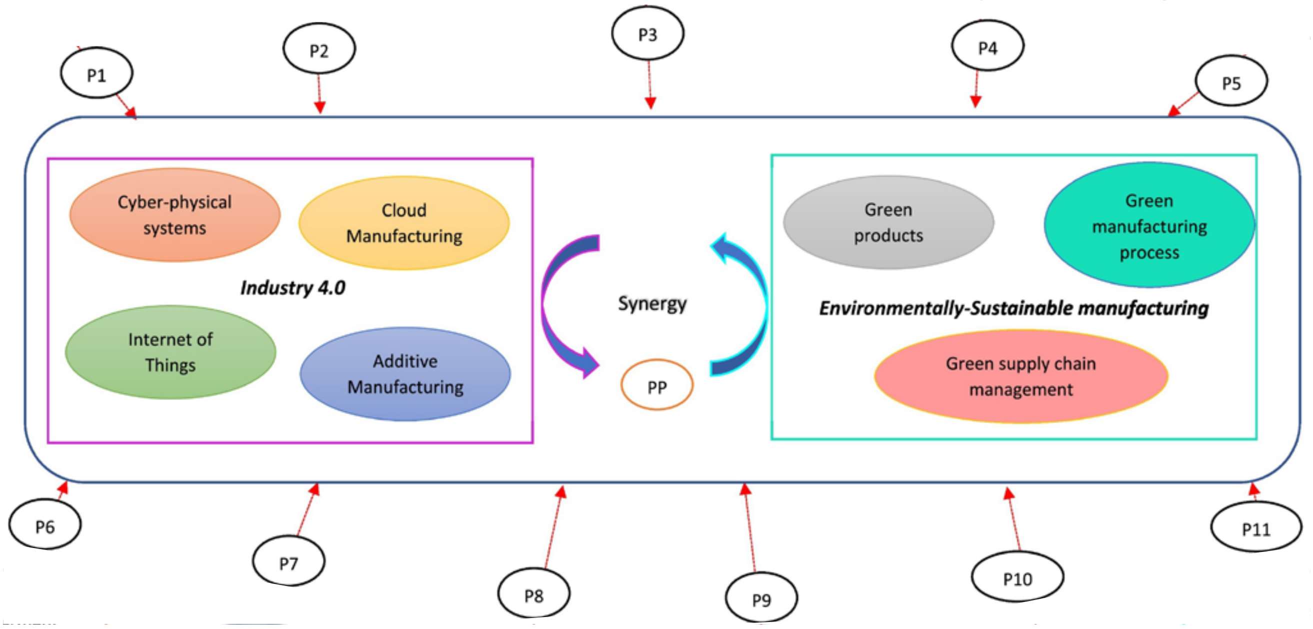

Fig.1 Integrative framework for understanding the synergy of Industry 4.0 and environmentally sustainable manufacturing [4]

Coolants and lubricants account for about 5% of the global lubricant market [9]. Approximately 85% of the applied cooling and lubricating fluids are mineral oil based. Estimated values, however, differ significantly due to the diversity of processes [10]. The main role of coolants and lubricants is cooling, reducing friction i.e. lubrication, removing chips from the space of cutting, and furthermore corrosion protection of the workpiece, cutting tool and machine tool [11]. However, the use of coolants and lubricants also causes disadvantages such as increased costs, negative environmental impacts and workers' health hazards (Figure 2) [12].

Traditionally, the abundant delivery of coolants and lubricants to the machining zone is uneconomical and environmentally-polluting. For machine industrial machining, the quantity and the type of coolants and lubricants is determinative. The "severity level" of the environmental load depends on the chemical composition, so environmental improvements are being made both to improve their quality and to reduce their quantity.

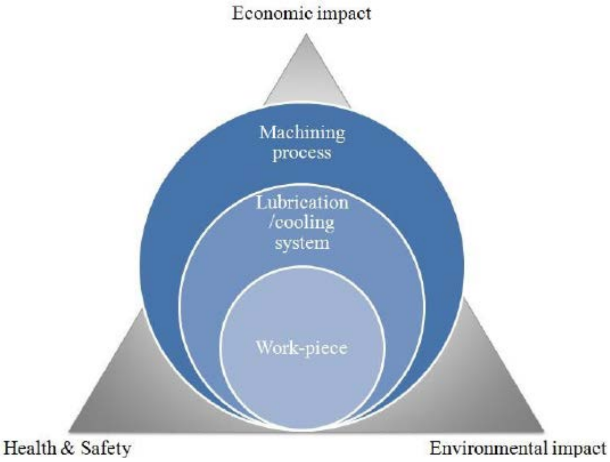

Fig.2 Economic, environmental, health and safety effects in sustainable production [7]

Possible directions for this:

- **Modification of consistency** by synthetic liquids (pure synthetic liquids and semi-synthetic liquids) or biodegradable natural oils (e.g. vegetable oils) instead of mineral oils [13].
- **Quantitative reduction** (minimizing cooling and lubricating fluids), reducing the volume flow rate of the introduced coolant and lubricant to a minimum quantity which almost completely disappears during the cutting process by evaporation or by adhesion to the chip and workpiece [14]. The reduction of the amount can be done until it is just enough to lubricate the cutting process. For minimal quantity lubrication volumetric flow rate of the coolant and lubricant is 10-100 ml/h. In this case, the cooling effect is negligible, nor does the washing effect apply.
- **Changing the state of the consistency.** When cooling with minimal volume fluid, the cooling effect dominates, and it is done mostly with compressed air, air-water or air-emulsion mixture [15].
- **Abandonment of coolants and lubricants**. Successful completion of dry machining operation is mainly achieved by cutting tool materials having high performance (high thermal and wear resistance).

Recently ecological solutions have also emerged. Using minimum quantity lubrication (MQL) good results have been achieved by researchers, for example, compared the previously mentioned so-called flooding cooling and lubrication. Kuzu et al. [16] studied the use of MQL for the machining of cast iron, Bashir et al. [17] for hardened steel, Gupta et al. [18] for a Ti alloy, and Sarikaya et al. [19] for the difficult-to-cut super alloy materials. Dhar et al. [20] obtained favourable results from the use of MQL related to tool wear and surface roughness when turning AISI 4340 steel. Khan et al. [21] emphasised the useful effect of MQL when applying environmentally conscious vegetable oil-based coolants and lubricants related to dry machining (turning) the material of AISI 9310 steel.

In addition to reducing the amount of consumption of coolants and lubricants this task has been solved so successfully that the reduction has no drawbacks but a series of benefits. Thus, when using MQL [22, 23], lower tool wear, longer tool life, reduced temperature, increased lubrication and improved surface roughness are obtained; generally, its application can provide better machinability. Sustainability of production can be achieved with minimal quantity lubrication [24].

We investigate all the procedures using the same type of coolants and lubricants (CL), with the goal being to reduce the environmental load by reducing the amount of CL or by completely abandoning it. Our research in these areas will be described below.

2 Experiments

The aim of the experiments is to improve the machining of gears of gearboxes in mass production, in which we want to reduce expenses and ensure that the load on the environment does not grow or even becomes lower. This is to be achieved by examining procedures for applying a different amount of CL to the unit of material removal rate (MRR) and to qualify as compared to the amount used in the previous procedure. As hardened surfaces are being machined, grinding and turning with CBN tools can be considered as an alternative method.

2.1 Workpiece

Case hardened gear (20MnCr5), hardness: 62±2 HRC, diameter of the hole: d1=38 mm, length of the hole L_3=29.85 mm, length increased by pre and over run: L_4 (L_4=L_3+1+1=31.85 mm), accuracy of the machined surface: IT5, roughness: Rz=5 µm. Series size: n=200 pieces.

The cutting data were selected for the various processes in such a way that the roughness and accuracy values provided in the drawings are always assured in every case.

2.2 Examined procedures

In the procedures, the widely used inner traverse grinding was considered as a base. This is justifiable because it is a widespread finishing machining procedure for hardened surfaces which practically creates topographies that meet all operational requirements. The expediency of examination of machining with geometrically defined cutting edges – with CBN inserts – is that it is possible to work with high material removal rates. The examination of two insert variants was done because of the applicable different feed rate values.

In our application, high productivity and shorter machining time can be achieved, but according to the sense periodical surface topography is created by turning. However, with built-in components, there are types of operating requirements for contact surfaces where such topography is inappropriate. This can be eliminated by using a combined procedure in which we intend to create random surfaces while still retaining as much as possible of the productivity of the hard-turning and of the advantageous surface layers created during the cutting process (i.e., from these two advantages). At this time, with the grinding following the hard turning, only the minimum allowance necessary to eliminate the periodicity is removed. This is most effective when turning and grinding is done on the same machine tool with one workpiece clamping. Procedures signed CPS and CPW refer to such a combined version.

The machining conditions are described for the procedures used in our experiments.

2.1.1 Conventional traverse bore grinding (TBG)

Machine tool: bore grinding machine type SI-6, cutting tool: 32×32×10 63B107C150R33V360. Geometrical data can be found in Fig.3 and technological data in Table 1.

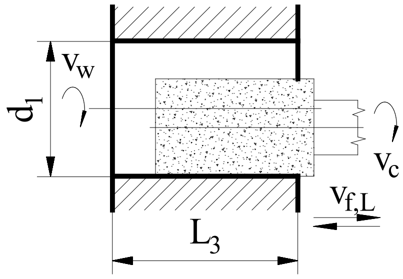

Fig.3 Geometric data for traverse bore grinding

Table 1 Technological data for traverse bore grinding

v_c, m/s	v_w, m/min	n_w, 1/min	i_{sp}
25	19	160	8
$v_{f,L}$, mm/min	a_e, mm/ds	f, mm/rev	n_{sp}, ds/min
R: 2200	0.020	13.75	36
S: 2000	0.001	12.50	33

Allowance in radial direction: Z=0.15 mm, divided for roughing Z_R=0.1 mm, for smoothing Z_S=0.05 mm

2.1.2 Hard turning (HTS, HTW)

Machine tool: Hard machining centre type VSC 400 DS (product of EMAG),

cutting tool: cutting tool holder: DCLNR 2525M12,

insert for roughing and smoothing NP CNGA 120408 GN4 MBC010 (**HTS R+S**);

insert for roughing NP CNGA 120408 G SW4 MBC010 (**HTW R**), and

insert for smoothing NP CNGA 120408 G N4 MBC010 (**HTW S**).

Geometrical data can be found in Fig.4 and technological data in Table 2.

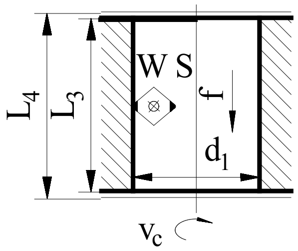

Fig. 4 Geometrical data (hard turning of bores)

Table 2 Technological data (hard turning of bores)

v_c, m/min	n_w, 1/min	a_p, mm	f, mm/rev
180	1508	**HTS**	
		R: 0.10 S: 0.05	R: 0.15 S: 0.08
		HTW	
		R: 0.11 S: 0.04	R: 0.24 S: 0.12

Values of allowance can be found in a_p column.

The acronyms in Table 2 are:

HTS – hard turning with standard insert,

HTW – hard turning with Wiper insert.

2.1.3 Combined procedures (CPS, CPW)

Machine tool: Hard machining centre type VSC 400 DS (product of EMAG), roughing is done by hard turning (data are according to Table 2), smoothing is done infeed grinding: tool: 32×40×8 97A602/5V112. Geometrical data can be found in Fig.5 and technological data in Table 3.

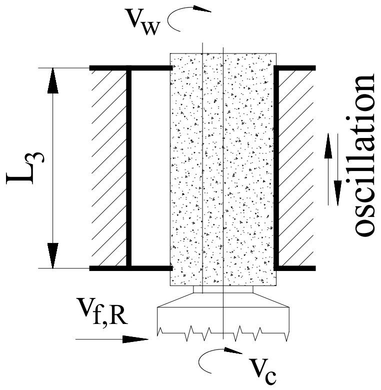

Fig. 5 Geometrical data, infeed bore grinding (only for smoothing)

Table 3 Technological data: infeed bore grinding (only for smoothing)

v_c, m/s	v_w, m/min	n_w, 1/min	t_{sp}, s	L_{osc}, mm
45	57	480	6	3
$v_{f,S1}$; $v_{f,S2}$, mm/min	$a_{e,S1}$, $a_{e,S2}$, mm	Z, mm, radially	Z_{S1}, Z_{S2}, mm	v_{osc}, mm/min
0.0050 0.0036	0.000625 0.000450	0.040	0.030 0.010	600

The acronyms in this sub-chapter are:

CPS – combined procedure when hard turning is done with standard insert,

CPW - combined procedure when hard turning is done with Wiper insert.

3 Results, Discussions

When the machining time is compared (Fig. 6), the grinding lasts for the longest time, its value is about five times more than the values of other procedures. It should be emphasised that the operation time of combined time procedures is almost the same as that of hard turning executed by standard insert. In addition to the operation times (Fig. 6) Table 4 shows the material removal rate and the consumption of coolants and lubricants.

Table 4 Operation times, material removal rates, consumptions of coolants and lubricants for the examined procedures

	Operation time T_{op} [min]	Material removal rate $Q_{w,op}$ [mm^3/s]	Consumption of coolants and lubricants	
			base is the computed machine time [%]	base is the operational time of grinding [%]
conventional traverse bore grinding (**TBG**)	4.069	2.19	100.0	100.0
hard turning (**HTS**)	0.826	10.79	0	0
hard turning (**HTW**)	0.657	13.56	0	0
combined procedure (**CPS**)	0.858	10.38	67.2	13.6
combined procedure (**CPW**)	0.803	11.09	76.6	12.4

Procedures replacing grinding can significantly increase the material removal rate.

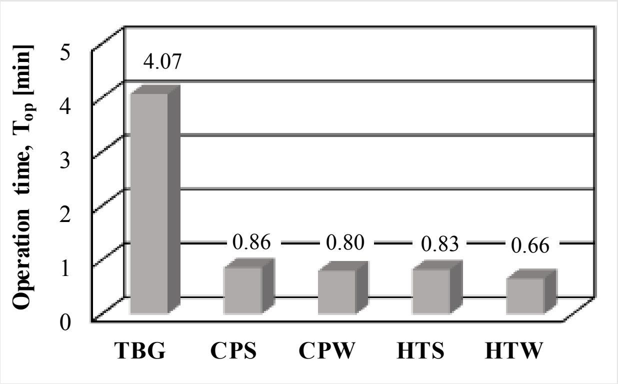

Fig.6 Operational time for the different procedures

When removing the same amount of material, then the operational time of other procedures using CBN inserts (hard turning) is only 16–21% of the time of grinding. This, of course, is also reflected in the values of the material removal rate (Fig. 7), as its value is 4.74-6.19 times per unit operating time.

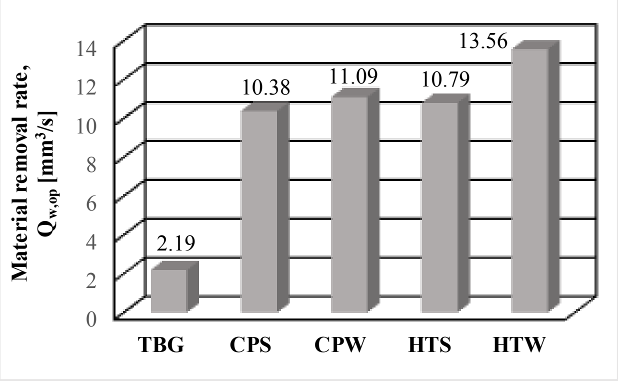

Fig.7 Material removal rate for the different procedures

When analysing variants using hard turning operations, it can be concluded that there is no significant difference between them, but the application of Wiper inserts using higher feed rates is favourable. If we analyse the procedures based on the coolants and lubricants used, the following conclusions can be drawn. The largest amount is required by grinding, the smallest is the hard turning because chip removal can be performed dry (without coolants and lubricants). Between them, the combined procedures can be found, for which the removal of the allowance is effective, – as previously described – grinding is performed for creation of the random surface. It is evident (Figures 8 and 9) that the combined process is more favourable related to the consumption of coolants and lubricants as well. This is clearly demonstrated in Figures 10–12. This means that combined procedures necessarily require the use of a coolant and lubricant, but to a lesser extent than conventional grinding, about 70% projected for machine main time (Fig. 8). When projected for operation time, only 13% of cooling lubricant is used in relation to grinding (Fig. 9).

Figure 10 shows the combined effect of a favourable change in operating time and the use of coolants and lubricants in the new procedures. It is evident that the machining task can be executed with lower environmental loads in shorter operation time.

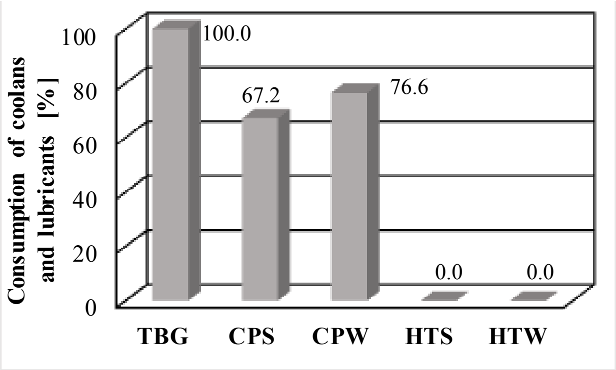

Fig.8 The extent of environmental load at the computed machine time for the various procedures

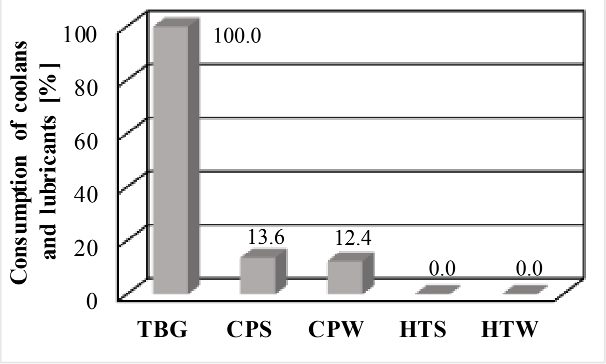

Fig.9 The extent of environmental load related to the operational time of grinding for the various procedures

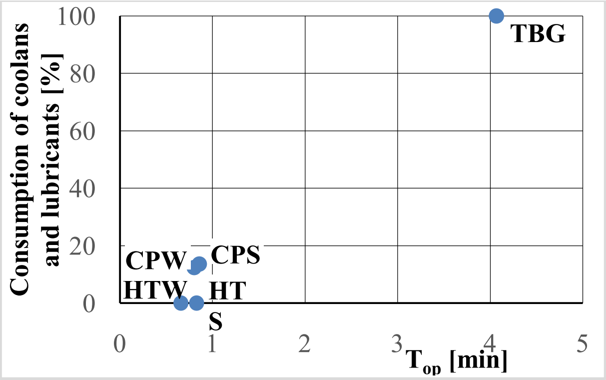

Fig.10 The extent of environmental load related to the operational time of grinding as a function of operational time of the procedures

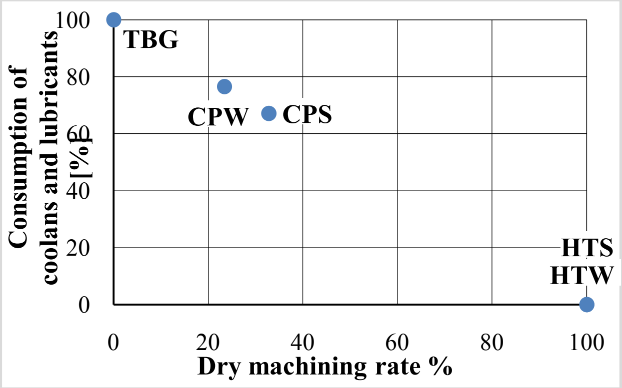

Fig.11 Rate of dry machining in the computed machine time for the various procedures

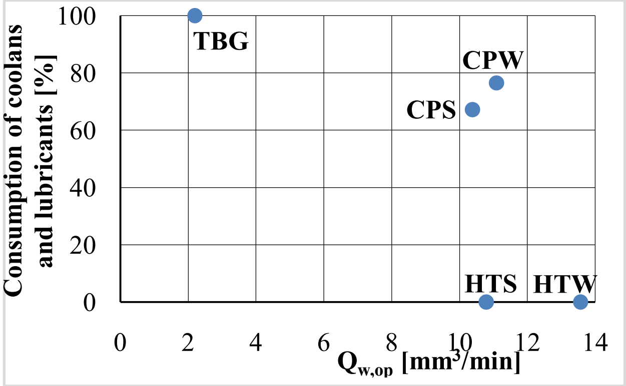

Fig.12 The extent of environmental load related in the computed machine time for the various procedures as a function of computed machine time

4 Conclusion

Based on the examinations presented in this paper, procedures can clearly be qualified based on environmental load. Compared to the conventional applied grinding, in hard turning procedures the amount of environmental load can be reduced so that the effectiveness indicators of chip removal do not diminish but are actually significantly improved.

If hard turning is involved in the production of random surfaces, the extent of environmental load can be reduced while productivity increases. A further research topic in the case of built-in parts requiring random surfaces, is a reduction in the grinding rate in the material removal (in the removal allowance) activity in the combined procedure, as this should also reduce the amount of coolants and lubricants.

In any case w here the periodic surface is acceptable, only hard turning is recommended, the efficiency of which can be further improved by the appearance of new tools.

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