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Technical-Economic Efficiency of Using Hard and Extra-Hard Material in Machine Tools

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Abstract: This research is an attempt to achieve maximum productivity of hard (H) and extra-hard material (EHM) tools with minimum cost in order to achieve economic efficiency of various technical processes. This study was based on various analyses of experimental data using algorithm model. The comparison is made with the technical-economic indexes of the technological process of existing tools. This paper attempts to analyse the nature of using hard and extra-hard materials and to develop a more comprehensive conceptual framework by using such materials to achieve effective operational management. The investigation proved that the use of diamond disc is more efficient and economical than that of silicon carbide stone (CSi). Although a diamond disc is 100 times more expensive than the silicon carbide stone, the total cost of operations is 33% less than when diamond discs are used.

Key words: Economic efficiency of tools, silicon carbide stone, diamond discs, technical processes

INTRODUCTION

The tools, which are made from hard and extra-hard materials EHM, are generally very expensive. Their use in the manufacturing processes, in some cases, depends on the costs of the equipment, high quality, special or specialized machine tools, changing of manufacturing technologies, etc. As a result, the problem of establishing the technical-economic efficiency always appear when these tools are in use.

The main problems that have to be solved when using means of hard and extra-hard tools are:

1. Technical and economical justifications for using tools made of H and EHM by determining, as exactly as possible, their efficiency.
2. Real determination for the need of using different H and EHM reinforced tools.
3. Making up the introduction and generalization of processing technologies, where tools made of H and EHM are used.
4. Technical personnel training to assure the right and rational use and exploitation of these tools.

Finding out the economic efficiency of introducing technological processes of manufacturing using H and EHM is necessary due to the following reasons:

1. Taking the right decisions regarding introduction of the new technologies as a function of the manufacturing quantity.
2. Perspective planning of the investments that to be done and their efficiency.
3. Planning of the savings, which will be obtained by introducing the new technologies.
4. Establishing the funds, which will be saved for scientific research purposes.

In order to determine the efficiency realized by use of H and EHM in machine building, the establishing of technical economic indexes should take place. Thus a classification of these well-known indexes, which concern the use of metallic cables, metal-ceramic, mineral-ceramic materials and diamonds with technical-economic efficiency, can be stated as follows:

Technical indexes: Enlargement of the cutting capacity, the value of cutting chip debit, processed surfaces quality, accuracy sizes, modification of the system working parameters and durability in exploitation.

Economical indexes: Cost of new tools, the repay time of the investments (tools, equipment and auxiliary materials), modification of working times, productivity growth, modification of elements which are composed the costs and minimising waste coefficient.

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Organization indexes: Modifications of the processing cycle, modifications of time rates, modification of the equipment positions in case of technological flow modifications, organization of semi-automated or automated manufacturing lines as function of the production volume.

Social indexes: No reduction (smoke, dust, etc), vibration elimination, noise minimisation, necessity of high qualification for the operating personnel and introduction of modern technologies.

Between majority of the already enumerated factors and indexes, there are tight relationship and reciprocal interaction[1]. For this reason, it is very important to make an analysis to a comparison basis. Thus, the obtained comparative data are systematised in order to estimate the annual savings that can be obtained by introducing tools made of H and EHM. The comparison basis will be established from the very beginning and the results of the efficiency calculation can be stated as follows:

1. The case of estimated determination of efficiency of introducing extra-hard materials processing technologies. The most advanced known and used techniques are used for comparison.
2. Determining of the dimension of the economical effect obtained by a company, since the introduction of the technological process of manufacturing or of the tools made of H and EHM. In this case as comparison base is considered the technical element (the tool, the technology) most used in the respective industrial branch.

Algorithm and calculations: The comparison is made with the technical-economic indexes of the technological process or existing tools, used before introducing those based on extra-hard materials (metallic carbide, fast steels etc.).

Generally, the introduction efficiency of using extra-hard materials, which are newer, is expressed by the realized annual economy and can be computed using the following Eq.:

$$E = (C_1 + E_N K_1) - (C_2 + E_N K_2) \quad (1)$$

where, E is the annual economy expressed in money units; C_1: cost of total production in initial conditions; C_2: cost of total production after introducing extra-hard materials; K_1: investments that is necessary for production (fixed and circulating means) in existing conditions, before introduction of extra-hard materials, refers to total production; K_2: investments necessary for production (fixed and circulating means) in conditions of introducing extra-hard materials, refers to total production; E_N: the normative coefficient of economical efficiency (usually $E_N = 0{,}15$). In every concrete case, the result that has to be achieved is maximum comparative value of efficiency or minimum reported losses, that means:

$$C_1 + E_N K_1 \rightarrow \text{minimum}$$

The actual economy, generated by introducing of H and EHM in manufacturing processes, can be determined also for the production unit, using the following Eq.:

$$E = (C'_1 + E_N K'_1) - (C''_2 + E_N K''_2) A_2 \quad (2)$$

where, C'_1, C''_2: the cost of current units before and after utilization of H and EHM respectively; K'_1, K'_2: Initial and subsequent specific investments on production unit respectively; A_2: the annual volume of production realized after introduction of H and EHM. The annual economy and the values of repay term of comparative recoverable investments (T_K); are estimated, which may appear as follows:

$$T_k = \frac{K_2 - K_1}{C_1 - C_2} \text{ (years)} \quad (3)$$

It is appreciated as favorable from technical-economic efficiency point of view, an investment repay term of 5-7 years. The industrial practice shows in majority of cases that the introduction of H and EHM in manufacturing processes is accompanied by investments recovered much faster (in some cases less than a year).

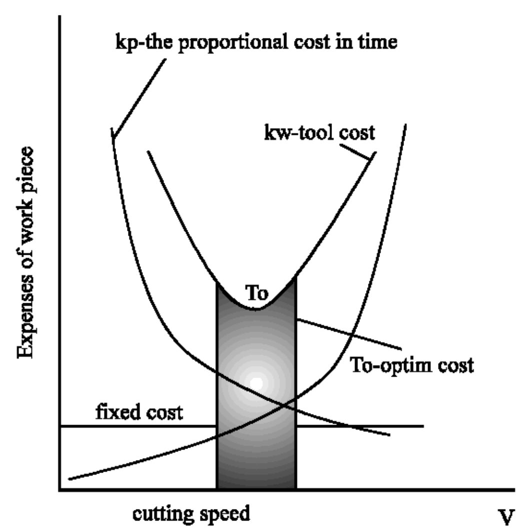

Fig. 1: Binary diagram shows the relationship between cutting speed and expenses of work pieces

The utilization of H and EHM not only reduces the production losses or specific consumption, but it also, considerably, increases the durability of end products. The economical effect of quality improvement can be determined using the following Eq.:

$$E = (C_1 + E_N K_1) - (C_2 + E_N K_2) + (C'_1 - C''_2) + E_N(K'_1 - K''_2) \quad (4)$$

where, $(C_1 + E_N K_1)$: the losses reported to annual volume of old production; $(C_2 + E_N K_2)$: the losses reported to annual volume of new production; C''_1, C''_2: the annual production costs in the old and new work ways respectively; K''_1, K''_2: are the supplementary investments at beneficiaries with regard to utilization of old and new products respectively. In the companies that are making these products, the economical effect generated by increased durability of products realized by means of H and EHM is greater than the one realized before introduction of H and EHM processing (Fig.1). The cost of a manufacturing operation by means of tools made of H and EHM can be determined using the following Eq.:

$$C = C_1 + C_2 + C_3 + C_4 + C_5 + C_6 + C_7 \quad (5)$$

where, C_1: material cost in (USD); C_2: cost of manufacturing; C_3: cost of exploitation of machine tool; C_4: cost of devices; C_5: cost of the tool; C_6: cost of pieces (semi-products); C_7: rent for the workspace.

The costs that have to be recovered in order to repay the investments, in case of using H and EHM are:

$$K = K_1 + K_2 + K_3 + K_4 + K_5 \quad (6)$$

where, K_1: is the cost covering purchasing or modernization of equipment; K_2: cost of devices; K_3: cost of working spaces; K_4: production administration; K_5: value of coefficient as a function of good pieces, which can be realized (0,9-1). Because of their properties, the tools made of H and EHM allow to work in intensive high productivity regimes so the machine tools need some special demands:

1. High speeds of tools fitted shafts.
2. High rigidity of technological system, respectively reduction to minimum of vibrations.
3. Advances automation.

Moreover, the high durability of the tools made of H and EHM allows and even imposes their utilization in automated production lines, e.g., at honing with diamond disc, the medium durability of a set of blades increases 100-10000 times than in case when conventional blades are used.

The systematized data regarding the individual economic efficiency is compared in order to establish the economical effect in companies, production branches and finally national economy. Any kind of mathematical model (Graph's theory, Perth's optimization method etc.) has, as a final result, the same desideratum for technical-economic efficiency, minimum cost and possible highest efficiency.

When estimating the technical-economic efficiency of using H and EHM in machine tools, it is very important to determine the necessary quantity of tools in order to introduce and generalize the working technologies using these materials. For this reason, the following steps have to be done:

1. Necessary tools structure analysis in order to minimize type dimensions which will be used.
2. Utilization of hard and extra-hard tools dynamics analysis based on annual and perspective plans.
3. Justification of consumption rates in order to decrease it.

All these allow us to make the technical-economic prognosis of development, production and utilization of tools made of extra-hard materials. The maximum economical efficiency of H and EHM utilization cannot be obtained without having a good planning and organization of introduction and generalization of these tools utilization.

For this reason, the following aspects have to be taken into consideration:

1. The technical propaganda-necessary to show the results obtained by means of using extra-hard materials in the country and in world-wide technique.
2. The introduction and finally generalization of planning using H and EHM.
3. Organization of production and supply.
4. Evidence and pursuit of H and EHM tools utilization;
5. Economic stimulation for introduction of H and EHM utilization.

The results obtained in industry are pointing out the increasing of technical-economic indices, which is a fact, which imposes, on a larger scale, the introduction of tools made of H and EHM[2].

The economical effects by means of diamond discs

The main advantages and utilization of diamond discs, which are processed through grinding and sharpening, are[3]:

1. Quality enhancement of processed pieces; the pieces can be processed with a precision limit of 0.001 mm with roughness R_a = 0.6-0.4 μm.
2. Work productivity Increase; the specific cutting chip debit increased from 60-300 mmc/hour to 2000-10,000 mmc/hour when using diamond tools.

3. Production price reduction by 2-3 times.
4. Processing technologies improvement and the possibility to process materials, which couldn't be processed in other way (WC, alloys with Mo, Ta, Co, ferrite, duroplaste, etc).

The cost of grinding or sharpening operation is determined by using the following simplified Eq.:

$$P_c = \frac{P_d}{N * D} + \frac{C}{D} \text{ (USD)} \quad (7)$$

where, P_d: price of the disc, in USD; N: number of pieces manufactured in an hour; D: computed durability of the disc expressed in hours; C: hourly cost of wages (containing company internal expenses and amortization rates).

From this Eq. it is obvious that this cost of the operation varies the inverse proportional with N and D. But the high productivity and the high durability of the tool are the main characteristics of the diamond discs.

Tools sharpening by means of diamond discs: The largest utilization of diamond discs is the processing of metallic carbide, especially in sharpening; the cutting tools use abrasive or detachable plates.

It is important to point out the aspects, which are connected with the economies that can be obtained by generalizing the method of sharpening by the tools with diamond discs.

Although a diamond disc is 100 times expensive than CSi stone, the total cost of operation is 33% smaller when diamond discs are used (Table 1).

Estimation about the size of the economies that can be obtained for a sharpening unit of a big machine-building factory sharpens annually, in average 5000 lathe tools using abrasive plate is:

1. The cost of a sharpening operation using abrasive stone made of silicon carbide is:

$$P_c = \frac{P_d}{N * D} + \frac{C}{D} = \frac{100}{10 * 10} + \frac{40}{10} = 5.0 \text{ (USD)}$$

2. The cost of a sharpening operation using diamond disc is:

$$P_c = \frac{3000}{50 * 60} + \frac{40}{60} = 1.66 \text{ USD}$$

3. The economy resulted for sharpening of a tool is:

$$e = 5.0 - 1.66 = 3.34 \text{ USD}$$

4. The annual economy will be:

$$E_1 = e * N = 3.34 * 5000 = 16.700 \text{ USD/year}$$

Table 1: Comparative values of the costs regarding grinding on the edge of metallic carbides plates

Processed piece	CSi stone K_{10}	Diamond disc K_{10}
Machine	Agathon 220P	Agathon 220P
Tool	Pot 140/170 Mesh	6A2-220-8-2; D90-75-R(Winter)
Number of grinded plates	913	913
Volume of removed material, kg	0.75	0.75
Ware of the tool, cmc	0.8	1.2
Work time, min/piece	2.5	1.35
Hourly cost, USD/min	0.0835	0.0835
Cost of machine and wages, USD/piece	0.0208	0.0113
Cost of the tool, USD/piece	0.0021	0.0042
Total cost of operation, USD/piece	0.0230	0.0153

The industrial practice demonstrate the fact that the durability of tools sharpened with diamond discs increased in an average of (1.5–3) times compared wit the conventional abrasive stones sharpening (Table 2).

The operation-large slide-bar grinding 40x700 mm. As perfect as possible processed surface flatness is required.

Considering the minimum value through which the durability is increased, the economics results from this increase can be pointed out in the following relations:

1. The number of possible re-sharpening of a tool is:

$$n = M/m = \text{(re-sharpening/knife)}$$

where,
M = Materials removed though reshapings.
M = 0.7 * b (a * b sharpened face dimensions).
m = Materials removed though one reshaping.

The average dimension of the tool is considered as a * b = 25 * 25 mm

$$M = 0.7 * 25 = 17.5 \text{ mm}; \ m = 0.4 \text{ mm}$$

The medium durability of a tool sharpened with conventional stone in average, is 60 min.

1. The total durability of sharpened tools can be shown in the following way:

$$T = t * n * N \text{ (min)}; \ T = 60 * 43 * 5000 = 1290.000 \text{ min.}$$

Table 2: Guides diamond grinding for the hard cast iron frames

	Conventional processing method	Diamond processing method
Machine tool	Plane grinding machine Favretto - RTC 400	idem
Method of processing	Complete grinding using oala stone made of CSi; Norton BD – 16 (150 * 16)	Milling with ceramic plates reinforced milling machine 2 passes finishing using diamond disc. Diamond Brait T55-2-80/100-C110-X344M (cutting depth 0.02 mm/pass)
Obtained results	Good roughness Relative flatness Difficult observation of tolerances Stone clogging 8 - 10 cleanings/piece Operations for retouching the piece are performed	Good roughness Perfect flatness Precise observation of tolerances The disc does not charge, is not necessary to be cleaned when a piece is processed Retouching of the piece is not necessary.
Manufacturing cost	15 USD/piece	9 USD/piece (covers also the cost of wear amortization of ceramic plates milling machine)
Work time min/piece	120	95

Table 3: Results of the determined comparative conditions between abrasive stones and diamond discs

	Old technology	New technology
Tool	Electrocorundum stone 46 K, ϕ 22 * 26	Diamond rod - Boart diamond ϕ 16 * 10 - Y80 - 100 - 24ST * 11
Obtained roughness Ra, μm	0.6	0.4
Tool wear	530 mmc for 900 mmc removed material	Insensible wear for 450 mmc removed material
Volumetric efficiency	1.7	530
Work time min./piece	52	30

Table 4: The cost results of the determined comparative conditions between abrasive stones and diamond discs

	Electrocorundum cutting	Borazon cutting
Tool cost, USD/cmc	0.10	0.32
Cost of 1 working hour on the machine, USD/h	20.00	20.00
Cost of 1 cmc removed material, USD/cmc	1.40	1.02
Machine amortization cost for 1 cmc removed material	1.40	0.70

In case of diamond disc sharpening, considering the durability as being 50% greater; the extra durability will be as follows:

Considering that the durability of a tool sharpened with diamond disc is:

t' = t + 50% = 60 + 30 = 90 min.,
a tool can work (t * n) h until its exhaustion.
t' * n = 90 * 43 = 3870 min = 65.4 h.

When diamond disc sharpening is used, the annual time economy reported to total durability of a tool will be equal to the number of tools which could be saved annually.

Considering that the medium value of a tool is 100 USD, the economy will be:

E_2 = 328 * 100 = 32.800 USD/year

The total annual economies will be computed by summing the economies obtained from the price of abrasive tools:

E = E_1 + E_2 = 16.700 + 32.800 = 49.500 USD/year.

Tools sharpening using diamond discs: While cutting tools sharpening, almost 80% from the consumed energy is transmitted to the piece as heat. The temperature at the tool-piece contact point may vary between 500-1000°C. This fact, generally neglected points to numerous modifications of superficial layer microstructure, being actually obtained the thermal treatment temperatures of the piece (tempering 1200°C, return 500-600°C). Thus, the following important modifications are produced:

1. Modifications of superficial structure of steel.
2. Modifications of durability.
3. Appearance of superficial tensions.
4. Appearance of micro cracks which, as a result, will have the following features: low cutting capacity; small durability and reduced reliability.

Sharpening of cutting tools by means of diamond discs eliminates the following disadvantages:

1. Reduced mechanical strains because of its high durability.
2. Low temperatures in the work zone.

3. Minimum wear, which induces high dimensional precision in exploitation.
4. Constant abrasive power without the necessity of rectifying during work.

The above findings lead to enhancement of sharpened tools, durability and reduced costs.

From the comparative conditions (Table 3), it is obvious that the wear of electrocorundum piece, comparatively with the diamond discs with ceramic binding agent leads to that the efficiency and cutting chip debit to be greater for the diamond discs. When the internal grinding of a bushing was performed with diamond discs, the following work regime was used:

n_{disc} = 14.000 rot/min.; n_{piece} = 30 rot/min.; V_{table} = 1 m/min.;
S = 0.008 mm; a = 0.15 mm.

For the sharpening of a milling machine made of steel tools with 13% Cr, durability 62 HRC, the following work regime was used: V_{disc} = 26 m/s; a = 0,02 mm; S = manual. The following values were obtained (Tables 3 and 4):

Where the Volumetric efficiency can be found as follows:

$$G = \frac{\text{Volume of removed materials}}{\text{Used volume of the tool}}$$

Cutting surface=8*30 mm; Cutting debit=0,48 cmc/min.; Efficiency G = 211. Out of these, for the case of sharpening with diamond discs, Ra =0.4 μm, comparative with 0.8 μm-value obtained for electrocorundum sharpening. The burnings of the superficial layer disappear and the time economy is approximately 60%. The durability of milling machines sharpened with diamond discs increases 2.5 times[4].

Introduction, utilization and rational exploitation of processing technologies by means of tools made of H and EHM is an important step in utilization of the modern technologies.

Utilization of these materials permits increasing of the cutting speeds, enhancement of precision and quality of processed pieces, raising resistance of wear and corrosion, raising of thermal stability for the pieces and tools made from H and EHM.

The new applied technology lead to the elimination of some operations and phases from the technological processes, because of special processing regimes, which are used allowing the achievement of high productivity at requested quality parameters. The above study points out the problems in connection with technical and economic efficiency of using H and EHM in manufacturing through cutting in the machine building industry. The characteristics of economic efficiency are followed by the economical effects of diamond discs grinding and sharpening and practical example of tools sharpening using diamond discs.

It is necessary to have a detailed knowledge of using H and EHM because of their big advantages: increased productivity, low price of the processed product, favourable conditions for mechanisation and automation, economic use of the material high precision. In order to project a good technology, it is necessary the knowledge of various and modern technological procedure, as well as the efficiency of using cutting tools made of H and EHM.

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