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ASSESSMENT OF MACHINABILITY OF METAL CUTTING

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ABSTRACT
The assessments of machinability of metal cutting are called "indices" and are derived by comparative research. These indices are the relations of two identical parameters, such as is the allowable cutting speed. The assessments were obtained at a constant tool life of 60 min, at the appropriate tool life minimum costs and the efficient reporting of specific restrictions for finishing and roughing.
Further the "scale of priority" is also used for the qualitative assessment of machinability.
Keywords: Cutting, machinability, cutting speed, finishing and roughing.

1. INTRODUCTION

The term "machinability" is supposed to mean the ability of metals to be treated by cutting [5]. Usually, it is measured by different technological parameters (indicators, benchmarks) – which are the allowable cutting speeds for the given tool life, the main cutting force, the roughness of the machined surface, the type and conditions of the rejected chip [2, 3]. The cost and material removal parameters of machining depend on the cutting conditions and on the allowable cutting speeds. Recently, other parameters are also in use. For example, productivity and machining time are also significant factors [6, 7]. The machinability of a metal is often assessed by comparative analysis [1]. Obviously, the demand for more accurate and more reliable methods of assessing machinability of metals is ongoing.
Very often, one mechanical product is compared to another one, or one technological process is compared to another process. Here, the objects are the machined metals, and the technological process is that of cutting. After comparing the technological, operational, economic and other considerations, one object or process is regarded as "referent". Despite the many advantages and opportunities of comparison, in some specific cases, it is only probable, subjective, and its role should not be taken for granted.
Comparative and benchmarking analysis can detect the presence or absence of differences in the different objects or processes, which have been adopted apriority.

2. MACHINABILITY INDICES

The discrepancy, needed for the eventual ranking of the research object in relation to another object, adopted as the "*reference*" object, has been quantitatively established during a comparative assessment of machinability. To this end, an I_0 ***coefficient of machinability*** has been introduced. It is obtained from the ratio of the two identical parameters, which are the allowable cutting speeds. These are obtained under certain cutting conditions [1]. Three types of indices of machinability have been analyzed.

1. *The index of machinability*, obtained by comparing the permissible cutting speeds when the life of the cutting tool is constant and the elements of the mode of cutting (f, a) are the same, but selected at random.

$$I_0 = \frac{v_c}{v_{c.em}}.$$

The index of the "*referent*" machined metal, $v_{c.em}$, is placed in the denominator where the larger values of the index are more favorably evaluated. Where the assessed $I_0 > 1$ machinability qualities are better than those of referent metal, the opposite statement is true, where $I_0 < 1$. $T = 60$ min is usually assumed for tool life.

The size and manner of change in the I_0 index varies for fine and rough machining and respectively for easy and heavy-duty conditions of cutting.

2. *The index of minimum machinability costs* is obtained from eligible cutting speeds, obtained by comparing the operating conditions, corresponding to the cutting process costs.

$$I_{0,k} = \frac{v_{c(K)}}{v_{c(K).em}}.$$

The indices $v_{c(k)}$ and $v_{c(k).em}$ match the tool life where the cost of machining ***K*** is minimal. They are determined by the so-called unconditional optimization of the cutting process. The lives of the researched metal and the reference metal have different values.

3. *The complex (optimal) index of machinability* is the relevant allowable cutting speed at which both the economic requirements (those achieving the minimum cost for machining technology) and the technological limitations (the allowable cutting force [Fc] for roughing or achieving the prescribed surface roughness [Ra] in finishing) are accounted for –

$$I_{00} = \frac{v_{c(0)}}{v_{c(0).em}}.$$

The object is the machining *technological production cost* of a surface to include the costs associated with the machining time (E) for surface processing, the costs for replacement of the worn-out tools and the costs of the instrument itself: (S):

$$K = t_M E + t_{CM}\frac{t_M}{T}E + S\frac{t_M}{T} \text{ or } K = t_M E\left(1 + \frac{t_{CM}^M}{T}\right),$$

where $t_{CM}^M = t_{CM} + \frac{S}{E}$ has been aligned to the machine time;

$t_M = \frac{L}{nf}$ – machining time;

$T = \frac{C_T}{v_c^{n_T} f^{y_T} a^{x_T}}$ – tool life dependence.

The equation of the technological cost $K = \frac{q_1}{v_c f} + q_2 v_c^{n_T -1} f^{y_T -1}$ is obtained after substituting

T and plotting $q_1 = \frac{\pi DLE}{1000}$ and $q_2 = q_1 \frac{t_{CM}^{M} a^{x_T}}{C_T}$.

The statistical models of the cutting force and of roughness of the machined surfaces, expressed as allowable values, are as follows:

– for roughing –

$$[F_c] = C_F^{'} f^{y_F} v_c^{n_F}, \quad \left(C_F^{'} = C_F a^{x_F}\right);$$

– for finishing –

$$[R_a] = C_R f^{y_R} v_c^{n_R},$$

Analytical dependencies on the optimal cutting speeds and the optimal feed have been obtained by the Lagrang, method outlined in [2].
The graphical interpretation of the results is the tangential point of the line expressing a restrictive condition and the objective function in a given parameter value [1]. Graphically, the line of cost is complex.

The comparison of the cutting processes is carried out under the same or different operating conditions. The comparison *under the same operating conditions* is warranted only in cases where the technical, technological, operational or economic reasons are justified or where they are the only possible. The comparison *under different operating conditions* only reflects the direct impact of a changing factor or changing factors.
Extremes, not matching the different cutting conditions [2, 5], have been observed for many of the regularities of the cutting process.
Objective evaluation by comparing two processes of cutting or machining of metal is obtained under such working conditions where there are corresponding minimal regularities of cost or of peak performance.

3. EXPERIMENTAL RESULTS AND ANALYSES
The estimates for machinability of alloy steels are subject to the following conditions: turning tool with a replaceable R25 material insert and allowable cutting force of $[F_c] = 5000N$. Inserts, made from P10 material, with a corner radius of $r_\varepsilon = 0,8\ mm$ and allowable roughness of $[R_a] = 5\ \mu m$, have been adopted for fine turning. The machined materials are 5HNM steel, conditionally adopted for reference and the researched (comparator) steels are 5H2MNAF and 4H5MFAS. The feed values f and the cutting depth correspond to those of fine machinability - the first two rows in tables 1, 2 and 3, and the last two lines – to rough machinability and within them are the easy mode (lines 1 and 3) and the heavy duty mode (lines 2 and 4). The table shows the values of the respective cutting speeds borrowed from [4] and indices of machinability.

The allowable cutting speed, v_{60}, the cutting speed for minimum cost, v_{ck}, and the maximum cutting speed, v_{co}, are predetermined by these models. The *"priority scale" PR [3]*, proposed by Andonov, for qualitative evaluation and comparison of machinability can be beneficially utilized. The priority is designated by the letters A to E, where PR $\approx$ C is the machinability of the reference metal corresponding to the $I_o = 0,89 \div 1,12$ interval. Table. 4 shows the verbal classification, the interval modification in the I_0 index and an indication of priority.

Table 1. Maximum cutting speed V_{60} and index I_0

No	Mode		Steel					
	f, mmr^{-1}	a, mm	50CrMo4		42CrMo4S4		34CrMo4	
			v_{60}	I_0	v_{60}	I_0	v_{60}	I_0
1	0,13	0,5	144,9	1	118,1	0,82	177,1	1,22
2	0,28	1,5	92,3	1	69,9	0,76	132,8	1,45
3	0,33	2,0	93,0	1	61,7	0,66	138,0	1,35
4	0,56	4,0	58,9	1	38,2	0,65	77,7	1,32

Table 2. Economical cutting speed v_{ck} and index $I_{0\,k}$

No	Mode		Steel					
	f, mmr^{-1}	a, mm	50CrMo4		42CrMo4S4		34CrMo4	
			v_{ck}	$I_{0\,k}$	v_{ck}	$I_{0\,k}$	v_{ck}	$I_{0\,k}$
1	0,13	0,5	181,4	1	180,9	1	195,6	1,08
2	0,28	1,5	115,6	1	107,1	0,93	146,8	1,27
3	0,33	2,0	127,9	1	150,2	1,17	149,6	1,17
4	0,56	4,0	81,1	1	74,6	0,92	122,7	1,51

Table 3. Maximum cutting speed v_{c0} and index I_{O0}

No	Mode		Steel					
	f, mmr^{-1}	a, mm	50CrMo4		42CrMo4S4		34CrMo4	
			v_{c0}	I_{O0}	v_{c0}	I_{00}	v_{c0}	I_{00}
1	0,13	0,5	153,6	1	164,2	1,07	190,3	1,24
2	0,28	1,5	130,7	1	134,6	1,03	166,8	1,28
3	0,33	2,0	79,9	1	69,2	0,87	96,5	1,21
4	0,56	4,0	97,9	1	95,7	0,98	129,1	1,32

Table. 4. Scale of priority

Machinability	I_0	*PR*
Dissatisfactory	$< 0,8$	*A*
Satisfactory	0,8–0,89	*B*
Good	0,89–1,12	*C*
Very good	1,12–1,25	*D*
Excellent	$> 1,25$	*E*

The relative nature of machinability of a grade of steel is expressed by the fact that a priority (PR) is prescribed for every finishing and roughing, and depending on the elements and values of f and a (see Tables 1, 2 and 3). This, in practice, determines the difficulty of the use and application of the priority scale. On the other hand, it is a starting point for managing the process of cutting and finding "better" working conditions.

4. CONCLUSION

The quantitative assessment of machinability, through the various indices, is only relative and depends largely on the operating conditions. The index of maximum machinability, however, also depends on the feasibility requirements for machining, during the processing time associated with the machine, t_{CM}^{M} , upon which the machinability index I_0 does not depend.

The minimum technological production costs for maximum cutting conditions and the so determined index of maximum conditions of machinability provide an opportunity to assess the metal cutting processing more comprehensively, more accurately and more objectively than previously used for this purpose indicators.

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