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Application of Tribometer Measurements for Evaluation of Machinability

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Investigation of machinability of materials is continuously faced with new demands, new principles and new achievements. The outcome of evaluation of machinability presented in this paper resulted out from observation of two tribological parameters: coefficient of friction and width of the wear area on contact between two sliding bodies, blocks and discs. Measurements are performed on tribometer in condition of wet sliding while one body is sliding over the other. A block is made of material which is usually used for cutting tool, and a disc is made of material which is used as a material of workpiece. Achieved contact condition (normal loading and sliding speed) meets real machining-cutting condition. The aim of the tests performed on tribometer "Block on Disc" is to evaluate the opportunity of investigation of materials machinability by tribological parameters (coefficient of friction and width of wear area on the block). Comparison of experimental results obtained during real cutting condition setup and tribological setup show a good correlation between wear values and cutting forces. For certain conditions, it is possible to acquire machinability indexes obtained on a tribometer with respect to friction coefficients and wear on the block as relevant and representative for real cutting condition.

Primjena tribometra u istraživanjima obradivosti materijala

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Kod ispitivanja obradivosti materijala kontinuirano se uvode novi zahtjevi, nove postavke i nova poboljšanja. Rezultati ispitivanja obradivosti, prikazani u ovom radu, proizašli su iz analize dvaju triboloških parametara: faktora trenja i širine traga trošenja na površini klizanja dva tijela, bloka i diska. Mjerenja su provedena na tribometru pri klizanju jednog tijela po drugom uz podmazivanje. Blok je izrađen od materijala koji se koristi za izradu reznih alata, a disk je izrađen od materijala koji se koristi kao materijal obratka. Ostvareni uvjeti kontakta (normalna sila na površinu i brzina klizanja) odgovaraju stvarnim uvjetima obrade rezanjem. Cilj ispitivanja provedenih na tribometru "Blok na disku" je određivanje mogućnosti ispitivanja obradivosti materijala pomoću triboloških parametara (faktora trenja i širine traga trošenja). Usporedbom rezultata dobivenih tijekom ispitivanja obradivosti u realnim uvjetima i na tribometru, uočena je dobra podudarnost vrijednosti istrošenja i sile rezanja. U određenim uvjetima ispitivanja, rezultati dobiveni na tribometru s aspekta faktora trenja i trošenja na bloku, mogu se prihvatiti kao reprezentativni pokazatelji obradivosti materijala u realnim uvjetima rezanja.

Keywords

Friction
Machinability
Simulation
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Ključne riječi

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1. Introduction

Reduction of friction coefficient and intensity of wear appearing on contact surface of two machine elements in relative movement, leads to a saving of driven energy and extends the exploitation life. The main source of increased losses of material and energy originates in the friction value of a tribomechanical system [2]. Reduction of losses and better performances of materials respectively ensure lowering of costs. The benefits of better mechanical properties of materials arising from improvements of material and development of new materials resolve the trigger majority of exploitation wear problems, but consequently problems during the production (machining) of these materials. Rapid growth of automotive and airplane industry, rocket technique, energetic and processing industry etc., causes wide application of numerous types of new materials with satisfactory exploitation properties [1]. The most frequently used materials for this industry are high-alloyed steels and stainless fire resistant steels, carbon and alloyed tool steels, special alloys on the base of nickel and cobalt, multilayer and ceramics materials, etc. The majority of these materials have improved mechanical

Symbols/Oznake

F_t	- tangential force, N - tangencijalna sila
F_n	- normal force, N - normalna sila
F_1	- main cutting force, N - glavni otpor rezanja
F_2	- passive force, N - otpor prodiranja
F_3	- feeding force, N - otpor posmičnom kretanju
F_R	- resulting cutting force, N - rezultirajući otpor rezanju
$F_{R2,3}$	- resultant of pasive and feeding force, N - rezultanta otpora prodiranja i posmičnog kretanja
$I(F_i)$	- machinability indeks - indeks obradivosti
I_{inv}	- index of material - indeks materijala
a	- cutting depth, mm - dubina rezanja
b_{ref}	- wear area of referent material, mm - širina traga trošenja referentnog materijala
b_{inv}	- wear area of block, mm - širina traga trošenja na bloku
μ_{ref}	- friction coefficient of referent material - faktor trenja referentnog materijala
μ_{inv}	- friction coefficient obtained on tribometer - faktor trenja izmjeren na tribometru
h_k	- criterion of tool wear, mm - kriterij istrošenosti alata
v	- cutting speed, m/min - brzina rezanja
t	- time, min - vrijeme
φ	- relation coefficient $F_{R2,3}$ and F_1 - faktor odnosa $F_{R2,3}$ i F_1
χ	- main lead angle, ° - kut postavljanja glavne oštrice
χ_1	- supporting lead angle, ° - kut postavljanja pomoćne oštrice
r	- insert radius, mm - polumjer zaobljenja vrha oštrice
α	- face angle, ° - kut stražnje površine
λ	- edge inclination angle, ° - kut nadvišenja oštrice
γ	- rake angle, ° - kut prednje površine alata

properties and specific physical properties which improve their exploitation performances and reduce their machinability and formability from the standpoint of a forming and cutting process. Therefore, evaluation of machinability of difficult machine materials with new cutting processes, new cutting tools and also with new machine tools is an interesting topic for the scientists and experts involved in development of materials and manufacturing processes.

To fulfil extremely hard machining conditions in difficult machine materials, adequate selection of tool material and tool geometry is very important. The importance of hard machining condition is more significant for overcoming mechanical and thermal loadings which appear during cutting. Machining of difficult machine materials with tools made of high speed steels (HSS) and tools with carbide inserts (TM) is of special interest. It is not necessary to point out that in domestic industry, tools made of high-speed cutting steel are still in use: HSS for easy machine materials with low cutting speeds and HSS.E with increased contents of alloys elements (W, Co, Mo) for difficult machine materials. Carbide tools used for machining of difficult machine materials are TM with coatings and tungsten less TM (cermet) which has good ductility and strength of cutting edge [3].

Development of tribological measurement systems and methodology for investigations of adequate models enables simulation of cutting process on tribometer "Block on Disc", shown in Figure 1, as well as identification of tribological processes into both basic tribomechanic systems of this kind. A simulation of wear process analyse happenings in the contact zone of tool insert on rake face and chip, and tool flank face and machining surface of work piece. Investigations presented in this paper, and started with this aim are based on research of tribological phenomenon appearing in contact of two bodies (Block and Disc), while one body slides over another in the presence of cutting fluid. The block is made of materials of cutting tool and the disk is made of materials of machining work piece.

2. Conditions of investigations

Investigation of machinability for a certain number of difficult machine materials in real cutting process conditions is in our tests performed on lathe, with high-speed steel tools (HSS.E) and carbide tools (TM) during dry and wet cutting (with and without cutting fluids). The values of all of three cutting force components are

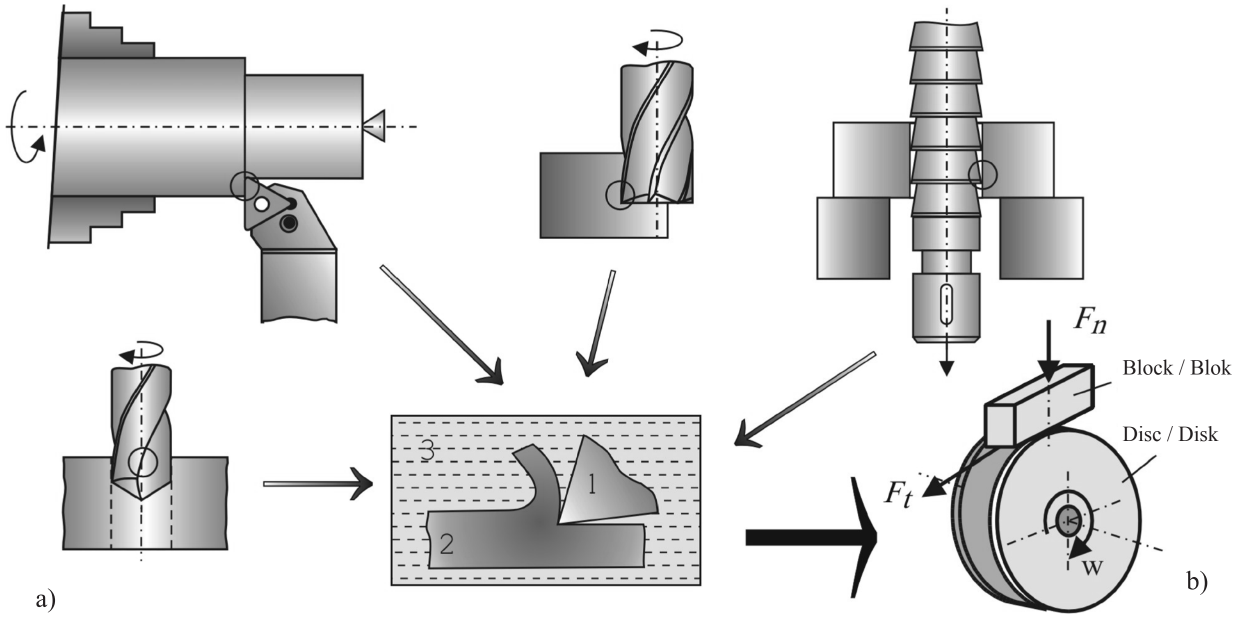

Figure 1. Tribomechanical systems: a) real machining processes and b) model

Slika 1. Tribomehanički sustav: a) stvarni process obrade i b) model

measured for different cutting regimes. Diagrams of tool wear dependence on time are obtained too.

Investigation on tribometer "Block on Disc" is performed after investigations on the lathe. Blocks were made of two materials: high-speed steels (HSS.E) and carbides (TM) which are commonly used for production of cutting tools. Discs were made of materials used for workpiece. This material has previously been used for investigations conducted on lathe. During investigation conducted on tribometer, the data of coefficient of friction and wear of contact surface between block and disc are obtained.

Conditions of turning tests on lathe were as follows:

Investigated materials: group of difficult to cut materials:

- 90MnCrV8 - 248 HB;
- X210Cr12 - 277 HB;
- 36CrNiMo4 annealed on 40 HRC;
- 55NiCrMoV6 - 258 HB;
- S6-5-2 (HSS) - 299 HB.

Cutting tools:

- high-speed tool steel - S10-4-3-10 (HSS.E): cutting tool ISO 10 (16x25x250 E18 Co10) with geometry: $\gamma = 6^0$; $\alpha = 8^0$; $\lambda = 0^0$; $\chi = 45^0$; $\chi_1 = 45^0$; $r = 1$ mm.
- carbide tool: insert SPGR 120308 PGP-135 (P35), PP CORUN; tool holder: CSDRP 2516 M12, KENAMETAL.

Machine tool: Prvomajska's universal turning lathe, driven power 10 kW.

Cutting fluid: cutting oil ISO 22

Cutting regime for HSS.E tool:

cutting depth 0,5 mm;

feed per revolution 0,112 and 0,14 mm;

cutting speed 20 and 40 m/min.

Cutting regime for carbide tool:

cutting depth 0,5 and 1 mm;

feed per revolution 0,14; 0,18 and 0,25 mm;

cutting speed 60 and 100 m/min.

Measurement equipment: three-component dynamometer KISTLER type 9265 A1, amplifier KISTLER, A/D converter Burb Brown type 2000 and computer.

Conditions of tribometer investigations were as follows:

Materials of block:

- high-speed steel S10-4-3-10 (HSS.E) of hardness 66 HRC;
- carbide without coating – SNUN 120412 in quality P30.

Materials of disc: group of difficult machine materials investigated on lathe.

Sliding speed: 0,74 m/s and 1,143 m/s.

Normal loading: 200 N and 300N.

Lubrication: boundary, realized by passing lower part of disc through oil bath, cutting oil ISO 22.

Duration of sliding contact: 60 min and 120 min.

Measurement equipment:

- Tribometer TPD-93 for measurement of normal loading, force and coefficient of friction.
- Talysurf 6- for measurement of parameters of contact body surface topography
- Universal tool microscope UIM 21- for measurement of wear of contact surfaces.

Results of tribological investigation contain data as follows: coefficient of friction, width and depth of wear area, wear shape of contact surface on block, change of friction coefficient during contact time, topography of block and disc surfaces before and after investigation, wear area on block and disc, etc.

3. Results of investigation

The machinability index can be estimated from input parameters of the process, and consist of one or several subfunctional machinability indexes. Measurement results of the surface roughness, tool wear and cutting force components can be used to determine machinability indexes [4]. In this paper machinability is defined from aspects of main cutting force F_1, passive force F_2, feeding force F_3, resulting cutting force F_R, resultant of passive and feeding force $F_{R2,3}$, and from the aspect of relation coefficient φ between resultant $F_{R2,3}$ and main cutting force F_1. These indexes are defined to enable comparison of different difficult machine materials. Steel 55NiCrMoV6 is chosen as a referential material, and machinability indexes are defined as follows:

$$I\left(F_{\mathrm{i}}\right)=\frac{F_{\mathrm{iref}}}{F_{\mathrm{iinv}}}\cdot 100\,. \tag{1}$$

Values of tool life are defined for certain process condition at adopted criterion of tool wear of h_k=0,2 mm for the tool made of HSS.E material and h_k=0,3 mm for the tool made of TM material. These values are defined on the basis of experimental defined curves of wear for the group of investigated materials.

Analysis of results originated from investigation on tribometer, calculation of machinability indexes and comparison of materials is done from two different aspects: from the aspect of friction coefficient measured on tribometer and from the aspect of wear area width on block at the end of experiment.

Steel 55NiCrMoV6, chosen as referential material for machinability indexes calculation has also been chosen for preliminary tests on lathe. Index of material, from the aspect of friction coefficient obtained on tribometer, is determined as follows:

$$I_{\mathrm{inv}}=\frac{\mu_{\mathrm{ref}}}{\mu_{\mathrm{inv}}}\cdot 100\,. \tag{2}$$

Indexes of materials are calculated from the aspect of wear area width on the block, obtained on the tribometer. Comparison of investigated materials has been done from this aspect on the basis of measured results of average width of wear area.

Indexes of materials from the aspect of wear area width on block *b* obtained on tribometer are determined according to:

$$I_{\mathrm{inv}}=\frac{b_{\mathrm{ref}}}{b_{\mathrm{inv}}}\cdot 100\,. \tag{3}$$

4. Comparative analysis of results

Analysis of measurements of cutting force on lathe as a valid machinability index are determined according to observation of several parameters (F_1, F_2, F_3, F_R, $F_{R2,3}$ and φ). Comparison of these measurements with results of measurement of friction coefficient on tribometer “Block on Disc” and indexes of materials from the aspect of friction coefficient obtained on tribometer, shows an appropriate correlation, that is an analogy between obtained results. Also, results of measurement of tool wear and wear area width on block, used for calculation of indexes of machinability from the aspect of tool life and indexes of materials from the aspect of wear area width, point to the existence of a correlation between obtained results.

Conditions of investigation on the tribometer correspond to the conditions of contact between tool flank face and machining surface. Thereat sliding speed is approximately equal to cutting speed, and normal loading is approximately equal to passive component of cutting force.

By comparison of results of investigation on lathe and on the tribometer (Figures 2 and 3), it can be seen that the best comparison between materials is obtained by indexes of machinability, which are calculated from the aspect of main cutting force F_1 and resulting cutting force F_R, and indexes of materials calculated from the aspect of the friction coefficient measured on the tribometer “Block on Disc”.

By comparison of results, it can be noticed that there is a significant coincidence of results obtained during machinability tests conducted on lathe from the aspect of main cutting force and indexes of materials obtained on the tribometer tests based on friction coefficient.

This correlation is related to all investigated materials except for steel 36CrNiMo4 in an annealed state, where certain deviation happened and can be explained by the fact that this steel is of great hardness (40 HRC) and changed structure (annealed state). That certainly points to the need for investigation of heat treatment influence, which is structure and hardness of materials, to machinability of materials from the aspect of machining in concrete condition of machining as well as from the aspect of tribological investigation.

Results of comparison of investigation done on the lathe and on the tribometer are shown in Figures 4, 5 and 6.

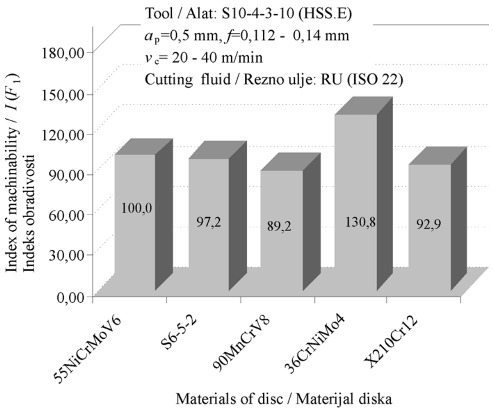

Figure 2. Indexes of machinability from the aspect of average value of main cutting force F_1

Slika 2. Indeksi obradivosti prema srednjoj vrijednosti glavne sile rezanja F_1

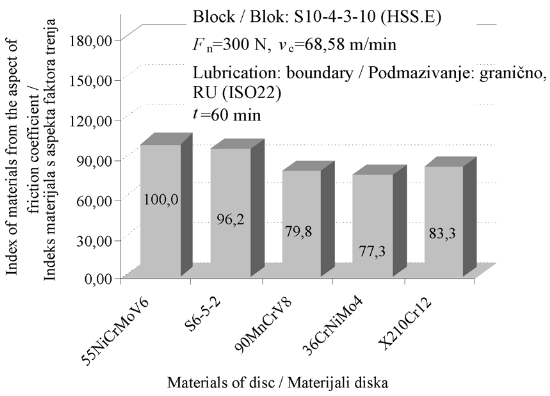

Figure 3. Indexes of materials from the aspect of friction coefficient measured on tribometer

Slika 3. Indeksi materijala prema koeficijentu trenja mjerenom na tribometru

Analyzing the results of investigation of tool wear at machining on lathe while using tools made of HSS.E and indexes of machinability of group of investigated materials formed on the basis of that results, it can be seen that there is an exceptionally high coincidence with results of investigation on the tribometer, where the wear area width on block were measured and indexes of machinability from the aspect of wear area width on tribometer were formed.

Correlation of results obtained during machinability tests from the aspect of tool wear and from the aspect of wear area width on block are almost the same.

Comparison of investigated results regarding the group of investigated materials machined on lathe with carbide tool and results of tribological investigation shows a strong correlation too.

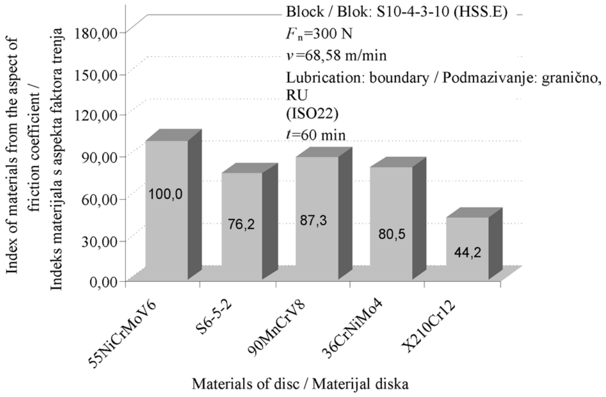

Figure 4. Indexes of materials from the aspect of wear area width on block made of HSS.E

Slika 4. Indeksi materijala prema širini površine trošenja na bloku izrađenom od HSS.E

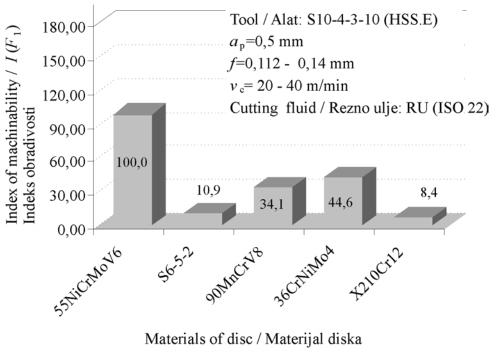

Figure 5. Indexes of machinability from the aspect of tool life for tool made of HSS.E

Slika 5. Indeksi obradivosti prema postojanosti alata za alat od HSS.E

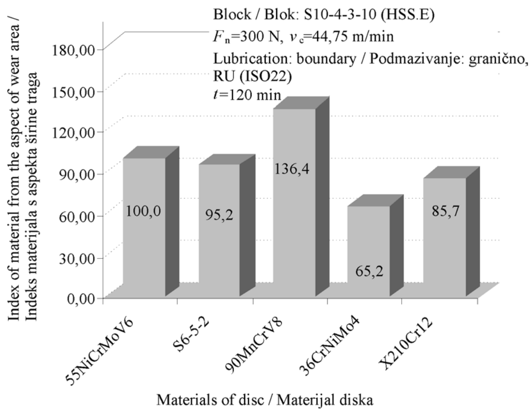

Figure 6. Indexes of materials from the aspect of wear area width on block made of HSS.E

Slika 6. Indeksi materijala prema širini površine istrošenja na bloku od HSS.E

5. Conclusion

A model for evaluation of machinability presented in this paper includes investigations of wear on tribometer with setup of the tribological pair as ‘Block on Disc”. Contact between two materials on the tribometer is achieved on line, which corresponds to conditions of contact between the clearing face of a cutting insert and machining surface of the work piece. Contact between tool insert rack face and chip can be modelled (simulated) too, by means of line contact between the block and disc on the tribometer for low cutting depth or feeds, which appears for small cross-sections of chip (fine machining conditions). For investigation of conditions related to rough machining (higher width and depth of cutting means greater cross-section of chip), contact is achieved by surface. Surface contact between block and disc could be obtained by “Pin on Disc” or “Ring on Disc” tribometer setup as a more realistic condition of investigation.

Since a very good correlation of real machining condition results are obtained with a relatively simplified test model, implications are that investigation of machinability could be performed satisfactorlly by means of tribological investigation on the tribometer “Block on Disc’. Originality of presented method could replace long-term and costly investigations of materials machinability with models for rapid investigations on the tribometer.

The next step in model development should be oriented toward approaching conditions of investigations on the tribometer with conditions of investigation on tool insert. This means accurate estimation of loadings and speeds on rack and clearing face of tool insert for each concrete case, which is applicable for a group of similarly investigated materials.

On the basis of the verified model for rapid investigations of materials machinability on the tribometer, the need and the idea of forming material machinability data base from the aspect of tribological investigation are imposed, which is one of the necessary directions of investigation in future.

REFERENCES

[1] MARUŠIĆ, V.; BUDIĆ, I.; ŠARIĆ, T.: *Istraživanje uzroka nastajanja škarta pri urezivanju navoja u čelične umetke tlačno lijevanih Al nosača dijelova motora*, Metallurgy, 46 (2007), 2, 135-140.

[2] MARUŠIĆ, V.: *Tribologija u teoriji i praksi, Strojarski fakultet Sveučilišta u Osijeku*, Slavonski Brod, 2008.

[3] NEDIĆ, B: *Simulation of cutting process on tribometer in order of developing new cutting fluids*, 4. DQM Conference, Vrnjačka Banja, 2001, Serbia.

[4] STOIĆ, A.; KOPAČ, J.; CUKOR, G.: *Testing of machinability of mould steel 40CrMnMo7 using genetic algorithm*, Journal of materials processing technology, 164-165 (2005), 1624-1630.