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Testing of machinability of 40CrMnMo7 steel using genetic algorithm

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Abstract: This paper deals with testing of hard materials machinability by high speed turning process and influence of cutting parameters on machinability rates. To determine machinability rates, surface roughness, tool wear and cutting force components were measured. In accordance with expected influence of certain parameter on machinability, experiments were designed and performed to determine mathematical models of the measured values over full response range. Obtained mathematical models were used for determination of machinability index and optimization of the parameters. Machinability was defined from input parameters of the process, and consists of one or several sub-functional machinability indexes.

Results of the testing can be used for more effective use of the machine tool performances, as well as for extension of the machinability testing of hard materials in different cutting conditions.

Keywords: Machinability, Goal function, Mathematical model, Genetic algorithm

1. INTRODUCTION

Development of new materials and manufacturing technologies has an effect on manufactures to adopt new condition in production and production strategies. If improper manufacturing resources (machine tools and procedures) are applied or if improper use of these resources arises, unfavorable future comes. New technologies, applied in metal removal processes set up new manufacturing condition as well as new procedures and methods for monitoring of machining process. Manufactures are faced with advantages and disadvantages of these new processes, but there is no simplicity in adoption of technological parameters and its machinability ratings. Topic of investigation and development of metal removal processes, defined by some researchers (Cebalo, Kuljanić, Kahn), is increase of availability of machining systems and its use in optimal cutting conditions. In the sector of manufacturing of mould tools, hard machining is alternative for ecologically and time unfavorable, grinding and discharge processes.

2. WORKPIECE MATERIAL REMARKS

The development of larger and larger plastic parts results in difficulties in the heat treatment of the moulds. In order to decrease these problems – possible dimensional changes and the occurrence of quench cracks – "tempered" steels are machined after heat treatment. The manufacturer heat treats them to a hardness between 280 and 400 HB/approx. (29 – 43 HRC). At this hardness, the steel can still be easily machined, but already has good wear resistance and sufficiently high strength.

Material used for medium/big sized moulds is steel 40 CrMnMo7 W.Nr.1.2311; and these moulds are applied for the automotive industry, for food industry, for the cosmetics industry, for rubber pressing, for pressure moulding etc. It is characterised with good polishability and texturing properties. This material has a homogeneous distributed hardness between the centre and the surface even on thick sections and good resistance to plastic deformations both in the centre and on the surface. The through hardenability is limited to approx. 400 mm thickness. The high micro-purity level and the consistent hardness between the centre and the surface give to this steel good suitability to polishing and photo-engraving. To increase the wear resistance it is possible to harden the die surfaces through nitriding. The hardness of the hardened layer after nitriding is about 900-1000 HV0,2.

Addition of sulphur in concentration of 0.05% to this steel offer better machinability, although its suitability for texturing and polish ability is limited. Physical properties of steel are : λ=33 W/(m·K) (20 °C), ρ=7,83 g/cm^3 , α = 13,5 10^{-6} ^{o}C^{-1} (20-300 °C). Hardness after quenching is 51 HRC (1730 N/mm^2).

Steel 40 CrMnMo7 is develop for a work at high temperatures (850-1050^{o}C). Steel is heat treated with hardening 880^{o}C (100 min) and tempered at temperature 440^{o}C. Test sample was a bar with diameter 200 mm and 60 mm long, fig. 3. Average hardness of test specimen was 45-47 HRC.

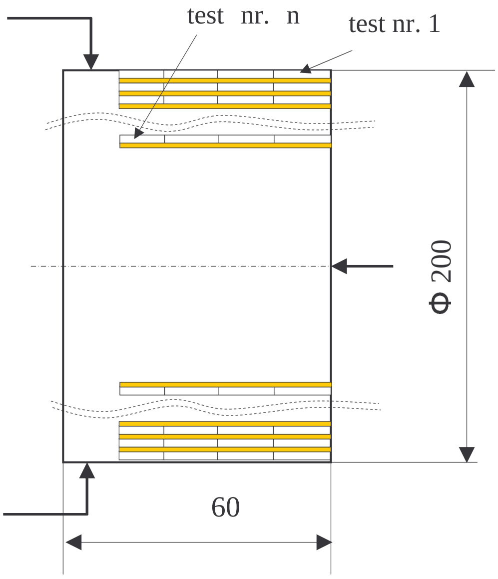

Figure 1. Shape of specimen used for testing

Table 1.
Chemical composition of specimen

Chemical Composition	C	Mn	S	Cr	Mo
Weght content , %	0,44	1,6	0,007	1,88	0,25

3. TESTING EQUIPMENT

Testing of machinability is performed on CNC turning machine Boeringer, main power 7,5 kW, $n_{\max}$ 4000 $\min^{-1}$. Test sample was tightened in chuck and supported with tip cone. Cutting tool was CBN 25, with geometry CNMA 1204__** TN3 (** - depending on tool radii). Tool was nested into holder PCLNL 2525M12 MED25100. Roughness was measured with table type device PERTHOMETER S8P 4.51 with head feeding into range 1,5-60 mm. Accuracy of head feeding was 0,2 μm/60 mm, referent profile length l_e=0,8 mm and observed length l_m=4mm (DIN 4762). Used filter had 75% filtering. It were measured values of *Ra* (DIN 4762, DIN 4768 and ISO 4287/1) and *Rmax* (DIN 4768). Cutting force measurement was performed with 3-channel KISTLER measuring device type 9257 B connected on data acquisition device Nicolett/ Odyssey with software Ver. 2.3. Analysis of cutting force measurement was done using MATLAB software. Cutting tool wear measurement was performed with SMARTSCOPE MVP2501588 Optical Gaging Products on table MSA6506 RSF Elektronik Austria. Output results were read values *VB*, *VB*max and digitized (scanned) photo of tool wear in TGA format. Analysis of scanned photo of tool wear was done with UTHSCSA Image Tools for Windows Ver2.0.

4. DESIGN OF EXPERIMENT AND RESULTS

Investigation was performed with four independent (input) variables : cutting speed , depth of cutting, feed and insert radius. Max. possible speed in our condition was 2500 m/min but at speeds higher than 800 m/min tool wear was to high and therefore two speed level were adopted (450 and 600 m/min). Depth of cut and feed were, because of physical properties of material, kept low ($f_{\min}$=0,1 mm, $f_{\max}$=0,2 mm, a_{pmin}=0,2 mm and a_{pmax}=0,35 mm). Insert radius r_ε was varied between range 0,4 and 1,2 mm. Experiment design was central composite design with 32 measurements (8 measurements in centre).

Five output variables were measured: two to indicate surface roughness (*Ra*, *Rmax*), and three to indicate cutting forces *Fc*, *Fp* and *Ff* . After the regression analysis was done, five mathematical models (1-5) of output functions were obtained :

$$Ra= 4,829001-0,006326\, v_c - 7,280413\, a_p+1,554342\, f-3,567335\, r_e+4,314476 \cdot 10^{-6}\, v_c^2 +15,833074\, a_p^2+20,124416\, f^2 + 1,776459\, r_\varepsilon^2 \quad (1)$$

$$Rmax = 22,90518-0,031697\, v_c - 40,28705\, a_p+12,75832\, f-14,26172\, r_\varepsilon+0,000023\, v_c^2 +89,81484\, a_p^2+43,083389\, f^2 + 7,466528\, r_\varepsilon^2 \quad (2)$$

$$F_p= -90,691873+0,336842\, v_c+144,92222\, a_p+55,271252\, f+27,830935\, r_\varepsilon - -0,000316 v_c^2+496,318047\, f^2-14,232008\, r_\varepsilon^2 \quad (3)$$

$$F_c = -43,377717-0,081213\, v_c+512,675309\, a_p- 23,581976\, r_\varepsilon+ 334,372727\, f+ + 0,000075\, v_c^2 +22,347589\, r_\varepsilon^2- 220,09046\, a_p^2-683,203536\, f^2 \quad (4)$$

$$F_f = -18,301841-0,013132\, v_c+177,903191\, a_p+163,199371\, f+9,995467\, r_\varepsilon^2- -215,924995 a_p^2-450,831238\, f^2 \quad (5)$$

Machinability (goal function) is defined as a function of one/several criteria and influenced with machining parameters :

$$MR_{\mathrm{tot}}= \mathrm{f}\ (\text{tool wear, machined surface roughness, cutting forces,}\ldots) = \mathrm{f}\ (v_c, a_p, f, r_\varepsilon) \quad (6)$$

Machinability testing starts when resources (machine tool, cutting tool and workpiece material) are known and is used to determine cutting parameters with best machinability rate. Machinability rates were determined with “Floating point genetic algorithm for minimization problems” Ver 2.0 /1999., developed at University de Moncton (Canada) in accordance with adopted boundary values of machining parameters. Results of machinability rate (in total - MR_{tot}) defined with few output measured values (criteria) and submachinability rates (only one machinability criteria) are shown in table 2.

Table 2.
Machinability rates and appropriate cutting parameters

Machinability		Submachinability rates				Machining parameters			
criteria	Rate MR_{tot}	MR_{Ra}	MR_{P}	MR_{Fc}	MR_{Fp}	v_c m/min	a_p mm	f mm	r_ε mm
$\frac{Ra}{P^*}$	0,518489	**0,600**	**0,864**	0,085	0,135	600	0,35	0,179	1,004
$\frac{F_p}{P^*}$	0,285692	0,413	**0,548**	0,543	**0,522**	600	0,265	0,171	0,4
$\frac{F_c}{P^*}$	0,388954	0,412	**0,530**	**0,734**	0,470	600	0,221	0,2	0,528
$\frac{Ra \cdot F_p}{P^*}$	0,192013	**0,853**	**0,417**	0,506	**0,540**	600	0,268	0,142	1,031
$\frac{Ra \cdot F_c}{P^*}$	0,225668	**0,663**	**0,487**	**0,699**	0,469	600	0,222	0,188	0,898
$Ra \cdot F_p$	0,882296	**0,993**	0,091	0,931	**0,889**	600	0,2	0,1	1,019
$Ra \cdot F_c$	0,9431758	**0,982**	0,091	**0,961**	0,890	600	0,2	0,1	0,892

* P=v_c a_p f - productivity

5. CONCLUSION

Results of machinability tests performed on tempered steel 40 CrMnMo7 (after hardening and tempering) present strong influences of machinability criteria on final machinability rate. To obtain multicriterial machinability function, early functional dependence of single criteria and machining parameters has to be defined. Functional dependence of single criteria is obtained after regression analysis of measuring results. Applying floating point genetic algorithm as an optimisation method, it is possible to determine machining parameters with best machinability rate. Limitations on number of submachinability rates are not pointed out in our work. As a result of these testing, the satisfied fit of machining parameters in certain cutting condition is possible.

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