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INFLUENCE OF OPERATING REGIME PARAMETERS ON WHITE LAYER FORMATION DURING A TURNING PROCESS OF HARDENED 16MnCr5 STEEL

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ABSTRACT
In this paper an analysis was carried out on characteristics and level of influence that operating regime parameters have on white layer formation during a turning process of hardened 16MnCr5 steel. Results of experimental research activities show that there is a close bond between an average thicknes of white layer (h_{sr}) and average arithmetic deviation of the profile of machined surfaceR_a. The above mentioned is expressed in high values for determination coefficients of acquired regression functions. Also, the results show that when machining hardened materials, characteristics of change for R_a, caused by change in operating parameters can be significantly different from the conventional machinig. Difference in change of characteristic for R_a can, in a specific way, be explained through effect of additional plastic deformation of generated white layer during the machining process of hardened steel.
Key words: Turning of hardened steel, white layer, additional plastic deformation of white layer

1. INTRODUCTION
Complexity of conditions that arise during turning process of hardened materials (HM) cause damage of machined surface, favorizing two main types of damage. The first one is so called white layer (WL), for which it is assumed that is a result of temperature generated on the surface of a work piece, and quick cooling afterwords. [1,2]. Other type of damage is formation of unwanted distribution of residual stress directly bellow the machined surface [1,2,3], causing occurence of micro cracks [5].
In the most reaserach activities in the area of turning hardened steel, WL was treated as a damage to machined surface, i.e. as a negative accompanying occurence of a process. It's been only latelz, that phenomenon of WL has begun being observed in the context of usage of its undoutable potentials [6,7,8, 9, 10]. Beside providing basic pre-conditions for the beginning as well as continuation of cutting process, parameters of the operating regime have a significant influence on its output characteristics too. In this paper, determination of level and characteristics of operating regime parameters' influence on WL formation, and itc characteristics during machinig of hardened 16MnCr5 steel, was carried out using metodology of a planned experiment.

2. EXPERIMENTAL RESEARCH ACTIVITIES

Round bars ϕ80x100 (mm) made of 16MnCr5 steel, after drilling holes ϕ50 (mm), were cut to length of 15 (mm). Chemical composition of machined steel is given in Table 1. Hardness of surface layer of work piece was within the interval 62 - 65 HRC. As tools the following were used: previously weared, ceramic cutting inserts, geometrical sign GNGA 120408T, aluminium-oxide base with Titanium-carbonitride (Al_2O_3/T_iCN).

Table. 1.: Work piece

Chemical composition of 16MnCr5 steel (%)	
C	0,14 - 0,19
Si	< 0,4
Mn	1,1 - 1,3
Cr	0,8 - 1,1
P	< 0,035
S	< 0,035

Table. 2.: Variation of operating regime parameters

Factor		Lower level	Basical level	Upper level	Interval of variation
Posmak	s (mm/o)	0.08	0.1	0.12	0.02
	x_1	-1	0	+1	
Cutting depth	t (mm)	0.1	0.2	0.3	0.1
	x_2	-1	0	+1	
Cutting speed	v (m/min)	100	125	150	25
	x_3	-1	0	+1	

Operating regime parameters were changed within intervals adequate for finishing operations (Table 2.), taking into account recomendation given by ceramic inserts manufacturers.
Experimental cutting tests included outside longitudinal turning on a CNC turning machine type INDEX. After tests of longitudinal turning and formation of machined surfaces, under machining conditions and in accordance with matrix plan given on Figure 2, work pieces were cut on a cat machine, pressed, polished and afterwards put in 3% solution of a nitric acid in alcohol.

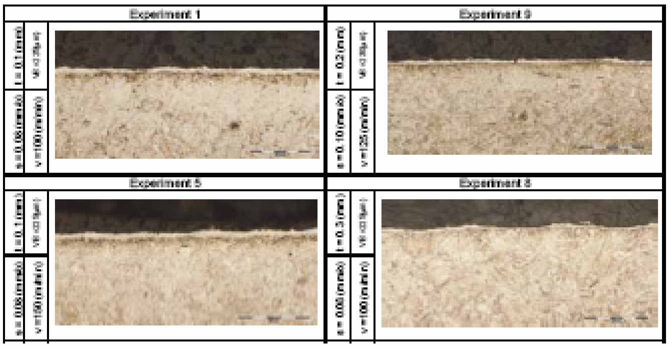

Fig.1.: Micropictures of machined surfaces with

Exp.	CODED VALUES				EXPERIMENATAL RESULTS		
	x_0	x_1	x_2	x_3	h_{sr}	R_a	h_{sr}/R_a
1.	+1	-1	-1	-1	4,592	0,70	6,560
2.	+1	+1	+1	+1	4,980	0,75	6,640
3.	+1	+1	-1	+1	3,627	1,01	3,591
4.	+1	-1	+1	+1	3,205	1,17	2,739
5.	+1	-1	-1	+1	4,670	0,60	7,783
6.	+1	+1	+1	-1	2,725	0,61	4,467
7.	+1	+1	-1	-1	2,705	1,00	2,705
8.	+1	-1	+1	-1	2,515	1,15	2,186
9.	+1	0	0	0	3,308	0,72	4,594
10.	+1	0	0	0	3,142	0,70	4,488
11.	+1	0	0	0	3,049	4,06	0,75

Fig. 2 Results of WL characteristics' measur.

Characteristc micro pictures of machined surfaces gebnerated during machining process, as well as results of performed experimental tests in accordance with matrix plan of first order, are shown on Figure 1 and Figure 2 respectively.

3. RESULTS AND DISCUSSION

Every output parameter was put in co-relation with oprating regime parameters, for five different regression types. For average thickness of WL (h_{sr}) and its relation to average aritmetic deviation of machined surface profile (h_{sr}/R_a), practicaly usable regression functions were reached. Types of functions with accompanying determination coefficents, as well as graphical interpretation of joint influence of operating regime parameters on h_{sr} for the regression function of rational type, are presented on Figure 3 and Figure 4 respectively. For reliable evaluation of h_{sr}, ratio h_{sr}/R_a, within observed variation interval of machining parameters, the following equations are recommended:

$$h_{sr} = \frac{1}{-0,7 + 9,765 \cdot s + 3,43 \cdot t + 0,004052 \cdot v - 22,2 \cdot s \cdot t - 0,0426 \cdot s \cdot v - 0,00768 \cdot v \cdot t} \quad ...(2.1)$$

$$(h_{sr} / R_a) = (5,866 + 210,5 \cdot s \cdot t - 42,1 \cdot s - 22,38 \cdot t + 0,0056 \cdot v)^2 \quad ...(2.2)$$

Influence of cutting speed on h_{sr} can be seen from always direct proportion, while characteristics of influences for feed rate and cutting depth can not be determined in general. But if obseved from the point of influence level then, it can not be determined in general for any of the machining parameters.

Influence of machining parameters to ratio h_{sr}/R_a is quite similar, both in type and level, to the one on h_{sr}. Cutting speed is in a direct proportion to analyzed ratio, while the influence type of feed rate and cutting depth is changeble, depending on other two machining parameters.

Output value	*Regression function*	*Shape of Regression functions*
h_{sr}	*Linear function*	$h_{sr} = 3{,}502 + 0{,}614x_1x_2 + 0{,}493x_3$ *(R^2=0,669)*
	Logarithmic function	$h_{sr} = \ln(47{,}93 + 34{,}57x_1x_2 + 21{,}64x_3)$ *(R^2=0,623)*
	Rational function	$h_{sr} = \frac{1}{(0{,}3 - 0{,}0444x_1x_2 - 0{,}0436x_3 + 0{,}025x_2 - 0{,}0213x_1x_3 - 0{,}0192x_2x_3)}$ *(R^2=0,955)*
	Exponential function	$h_{sr} = e^{(1{,}227+0{,}163x_1x_2+0{,}144x_3}$ *(R^2=0,683)*
	Quadratic function	$h_{sr} = (1{,}859 + 0{,}158x_1x_2 + 0{,}133x_3)^2$ *(R^2=0,676)*
h_{sr}/R_a	*Linear function*	$(h_{sr}/R_a) = 4{,}529 + 1{,}779x_1x_2 + 0{,}604x_3 - 0{,}576x_2$ *(R^2=0,956)*
	Logarithmic function	$(h_{sr}/R_a) = \ln(389{,}14 + 485{,}39x_1x_2)$ *(R^2=0,362)*
	Rational function	$(h_{sr}/R_a) = \frac{1}{(0{,}256 - 0{,}102x_1x_2 - 0{,}035x_3 + 0{,}033x_2)}$ *(R^2=0,946)*
	Exponential function	$(h_{sr}/R_a) = e^{(1{,}438+0{,}407x_1x_2+0{,}134x_3-0{,}128x_2)}$ *(R^2=0,982)*
	Quadratic function	$(h_{sr}/R_a) = (2{,}09 + 0{,}421x_1x_2 + 0{,}14x_3 - 0{,}133x_2)^2$ *(R^2=0,967)*

Figure 3 Results of regression analysis of experimental research

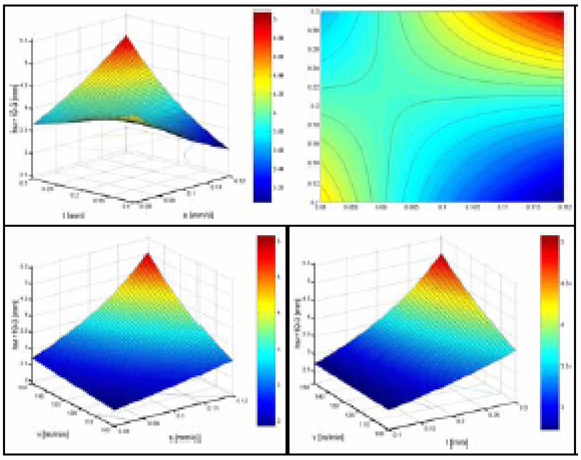

Figure 4 Joint influence of machining parameters on average thickness of WL

Level of influence of any of the machining parameters to the analysed ratio, like in this case, can not be determined in general . Mentioned trentds are clearly visible from Figure 4 and Figure 5.

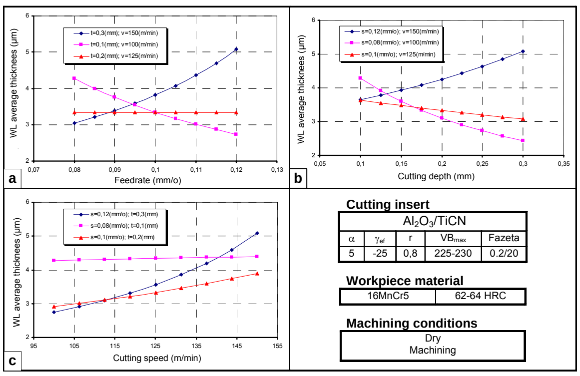

Figure 4 Influence of machining param.on h_{sr}

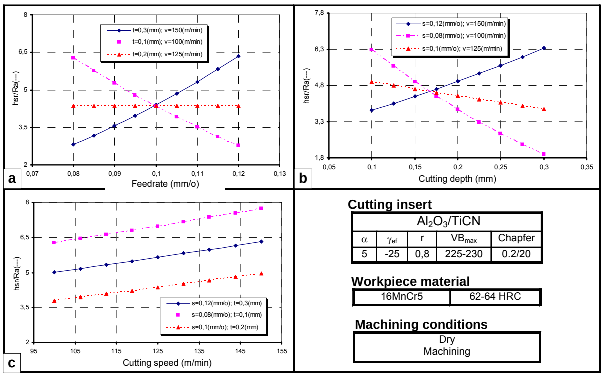

Figure 5 Influence of machining param on h_{sr}/R_a

Performed statistic evaluation of experimantal results did not result in adequate mathematical description of average arithmetic deviation of machined surface profile (R_a) as a function of machining parameters. Not even one of the five regression functions was practicaly usable, firstly due to insignificantion of a large number, and in some cases all, factors. Situation of not reaching adequate regression dependancy of R_a as a function of machining parameters, when turning hardened 16MnCr5 steel, in some way points to difference in type of its change (R_a) comparing to type of its change when machining similar materials but under conditions of conventional cutting. In accordance with the above stated a question arises: is a WL formation cause of these differences? With a goal of getting an answer to this question, and understanding type and influence level of machining parameters on R_a, when turning hardened material when there is a WL formation, mathematical dependancy was derived (2.3) using equations (2.1) i (2.2) .

$$R_a = \frac{1}{(-0{,}7 + 9{,}765\cdot s + 3{,}43\cdot t + 0{,}004052\cdot v - 22{,}2\cdot s\cdot t - 0{,}0426\cdot s\cdot v - 0{,}00768\cdot v\cdot t)\cdot(5{,}866 + 210{,}5\cdot s\cdot t - 42{,}1\cdot s - 22{,}38\cdot t - 0{,}0056\cdot v)^2} \quad ...(2.3)$$

Partial influence of machining parameters, during WL formation, to average arithmetic deviation of machined surface profile, in accordance with equation (2.3), are shown on Figure 5. Analysis of results shown on Figure 5, showed that it's obvious when turning hardened 16MnCr5 steel, types of influence of feed rate and cutting depth to R_a are the same. On the other hand, type of influence of cutting speed is completely different, comparing to influence of feed rate and cutting depth, regardless to cutting process conditions. When observing maximum values of machining parameters, significant differences are noticed regarding type of influence of machining parameters on R_a, comparing to their influence in case of conventional turning. Namely, cutting depth and feed rate are in inverse proportion, while the cutting speed is in direct proportion to R_a, i.e. R_a increases when cutting speed increases, while it decreases when cutting depth or feed rate increases.

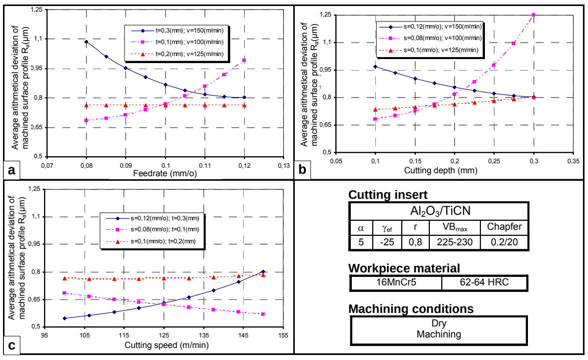

Figure 5 Partial influence of maching parameters to average arithmetic deviation

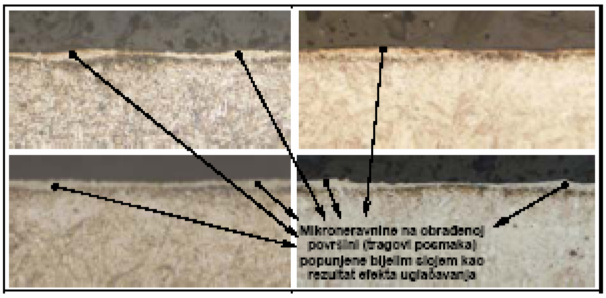

Figure 6 Micro pictures of generated surface with effect of additional plastic deformation of WL

Cause of such changes is definitely not only in WL formation mechanism, although it is undoubtly in connection with it. Such conclusion can be reached on the basis of the fact that WL formation occurs in cases with minimum values of machining parameters, without causing a change in type of R_a, comparing to conventional machining procedures (Figure 5.). In other words, WL formation, during machining of hardened 16MnCr5 steel, is not always followed by a change in the type of R_a. Therefore, it is certain that change of analysed type is caused, beside WL formation, by additional phenomenon or phenomena. Possible phenomena (cause of change of described caharacteristic of) arise as result of additional plastic deformation of WL (”polishing” of WL using flank surface of the tool due to its movement along the work piece axis), as well as possible impressing of certain amount of material from the un-cut layer of chip inside the machined surface. The effect of ”polishing” which follows WL formation process, under som machining conditions, as well as results of its influence, are visible on micro pictures of machined surfaces shown on Figure 6. As can be seen from the picture, the result of "polishing" is a machined surface with lower roughness then expected. In other words, micro unevens on a machined surface, due to effect of additional plastic deformation of WL (polishing) are being filled.

4. CONCLUSIONS

Based on the analyses of experimentaly reached results, presented in this part of research, the following conclusions are reached:

1. There is a close connection between h_{sr} i R_a, manifested in high values of determination coefficients reached regression functions.
2. When machining hardened materials, type of change of R_a, caused by change in machining parameters, can be significantly different comparing to its value when working under conventional machining conditions.
3. Effect of additional plastic deformation of generated WL during machining of hardened steel, can in some way explain difference in change of type of R_a. The above mentioned effect, if follows after WL formation, results in decrease of roughness of machined surface comparing to its programmed value.

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