THE DEPENDENCE OF THE PHYSICAL AND MECHANICAL PROPERTIES OF TOOL STEEL ALLOYS FROM THE TYPE OF MACHINING

ЗАВИСИМОСТЬ ФИЗИКО-МЕХАНИЧЕСКОГО СОСТОЯНИЯ ИНСТРУМЕНТАЛЬНЫХ ЛЕГИРОВАННЫХ СТАЛЕЙ ОТ ВИДА МЕХАНИЧЕСКОЙ ОБРАБОТКИ

Antonyuk V.S., doctor of technical sciences, professor [1], Volkogon V.M., doctor of technical sciences, professor [2],
Vysloukh S.P., Ph.D, docent [1], Avramchuk S.K, Ph.D[2], Fedoran Y.A. [2], Barandich C.S. [1]
National Technical University of Ukraine "Kiev Polytechnic Institute" [1],
I.N. Frantsevich Institute for problems of materials science of National Academy of Sciences of Ukraine [2], Kyiv, Ukraine
E-mail: vp@kpi.ua

The results of studies of the influence of the type of machining and tool material to the structural state of the surface layer and the fatigue strength of ХВСГsteel during machining are shown. Processing with the composite-10 tool in a surface layer for α - and γ - phases is accompanied only by compressing residual pressure while abrasive processing promotes occurrence of stretching pressure of an I-type. Increasing of cutting speed of the composite-10 tool from 50 to 200 m/min does not lead to significant changes in fatigue strength.

KEYWORDS: CUTTING, TOOL STEEL, GRINDING, TURNING, AUSTENITE, MARTENSITE, MICROHARDNESS, RESIDUAL STRESSES, FATIGUE STRENGTH

Introduction.. The impact of high temperatures and pressures in the cutting zone has a decisive influence on the formation of surface layers in the machining tool alloy steel. Structural changes occurring during this process depend on the value of the factors above, as well as the chemical composition and structure of the original material. Unlike conventional heat treatment, this changes happens in the course of plastic deformation caused by high contact pressure, speed of heating and cooling the surface layers of metal [1].

In the case of the machining of high-strength structural steels two zones of the structural state are formed in the surface layers: directly at the surface - area of secondary hardening and the surrounding area, corresponding to the structure of the quick high-temperature release. Depth of zones of structural changes in the surface layers of the steel at various machining types is determined by various combinations of temperature and pressure contact pairs [2, 3]. Machining of tool alloy steel with cutter has little effect on the strength and ductility of both soft and hardened steels, but has a significant influence on their resistance to cyclic stresses [4]. This is explained by the development of fatigue failure, usually from the surface and in a small volume; while every local weakening of the material causes a shift with tears and thus fatigue cracks later [5].

The grinding of tool steel alloys usually leads to a decrease in fatigue resistance, which is conditioned by the occurrence of tensile residual stress during processing [6]. The rough turning also reduces the fatigue resistance of structural and tool steels because of worst microgeometry of the surface. However, different types of turning have different effects on endurance, and more rougher the machining, the lower endurance will be in the details made of structural steel [7]. Therefore, fine turning with small feeds provides a surface with good microgeometry, a smaller number of defects (gaps, cracks, torns) and reinforcing effect. The most significant effect of turning on endurance of alloy steels have the rate of feed, the radius of the rounding of the cutting edge, the rake angle and the cutting speed [8]. The changing the depth of cut has little influence on the fatigue resistance of steels, since the microgeometry of the machined surface has no significant dependence of this parameter; and some increase in work hardening by increasing the depth of cut is offset by the growth of residual tensile stresses [9].

Usage of superhard cutting materials based on wurtzite boron nitride –composite-10, which has a high thermal conductivity, contributes to shift of the level of residual stresses and, consequently, improves the strength properties of the material [10, 11]. However, the question of using nitride ceramics in the processing of tool alloy steel by turning and grinding isn't studied enough.

Objective. Study the effect of the type of tool material and machining conditions on the strength characteristics and structural condition of the surface layers of tool steel alloy 107WCR5.

Study methodology. To study the effect of the type of tool material on the structural state of the surface layers of the studied steel 107WCR5 obtained by grinding abrasive wheels and turning cutters of composite-10. Technological process of manufacturing the samples consists of cutting round bars for workpiece, pre-turning, semifinished and finish machining. To study the effect of the grinding process of steel 107WCR5, hardness HRC 54 ... 56 samples were prepared in the form of cylinders of 10 mm height and 50 mm in diameter, and effects of turning - 250 mm long, which were hardened at a temperature of 850 ^{0}C (with cooling in oil) and tempered at a temperature of 200 ^{0}C in air.

Grinding was carried out on cylindrical grinding machines 3Б12 with abrasive wheel: 1A1 250x16x76 63C 6 CM1K and wheel 1A1 250x16x5x76 ГА 125/100 100% БСТ from composite-10.

Turning was performed on a turning machine 16K20 with cutters of composite-10 and different processing rates - the cutting speed V = 20, 40, 80, 160 and 250 m/min, feed s = 0,07 mm/rev and depth of cut t = 0,25 mm. X-ray studies were conducted by stratified analysis on a diffractometer ДРОН-3 in Fe K α-radiation. The amount of residual austenite (fγ) in the samples was determined from measurements of the integrated intensity of X-ray lines (110) and (111) α and γ-phases in view of repeatability factor:

$$f_\gamma = \frac{S_\gamma}{0{,}66 \cdot S_\alpha + S_\gamma} \cdot 100\% \qquad (1)$$

where S_α; S_γ – the integrated intensity of X-ray lines α and γ-phases, respectively. The numerical values of $S\alpha$ and $S\gamma$ are determined by computation of respective lines. I-type stresses in the surface layers were evaluated by X-ray diffraction as the sum of the principal stresses (σ1 + σ2) by the formula:

$$\sigma_1 + \sigma_2 = \frac{E}{\mu} \cdot ctg\Theta \cdot \Delta\Theta \qquad (2)$$

where E - modulus of elasticity; μ - Poisson's ratio; $\Delta\Theta = \Theta - \Theta_0$ - angle difference, K_α - components of α and γ phases after machining (Θ) and the original (Θ_0).Research of microhardness of the surface layers of samples was performed on microhardness tester ПМТ-3 with a load of 0.2 N and 0.5 N.

Fatigue test of samples were performed as a cantilever bend with rotation. The frequency of load changes was – 15.0 Hz, the test base – 10 million cycles. For curve fatigue plotting at least 15 samples were tested, machined according to the regimen. The resulting calculation of averages $\bar{\sigma}$, $\lg \bar{N}_p$, mean-squared departure of σ_i and $\lg N_{p_i}$ the correlation coefficient and others are the initial data to correlation equation - fatigue curve equation:

$$\lg N_p = A + M\sigma \tag{3}$$

where N_p - the average number of cycles to failure of the sample with stress σ; *A*, *M* - factors.

Evaluation. Studies of microhardness depending on the depth of the layer during grinding with abrasive wheel and turning with cutters of composite-10 showed that the depth of the zone of the secondary quenching decreases with increasing thermal conductivity of the tool material processing. In this case area of high-temperature tempering have a depth of 30-650 microns for grinding wheel, , and 8-12 mm in the case of turning cutters of composite-10. Thus, when the temperature drop in the processing zone, the depth of the damaged layer is reduced and becomes a minimum for the surface processed with turning by cutter of composite-10.

The results of measurements of residual austenite after grinding by abrasive wheels and after turning by cutter of composite-10 shown in Table 1. As seen from Tables depth of austenite impaired concentration is by several times less than the depth of impaired microhardness and when processing with abrasive wheel is equal to 120 microns by cutter of composite-10– 80 microns. Noticeable changes in the concentration of retained austenite during the turning by cutters of composite-10 occur in the range of *V* = 20-80 m/min. It can be associated with the process of adhesion of the processed material on the cutter as described in [5, 7].

The structural state of the surface layer of the studied steel during turning with cutter composite-10 (Fig. 1, a-d) is characterized by compressive stress area during α- and γ-phases, maximal at the sample's surface. The subsequent behavior of the stresses in depth for the α- and γ -phase varies and depends on the cutting speed. To investigate the rate of the minimum in γ-phase is reduced to zero at a depth of 60 micron. A characteristic feature of the process of grinding with abrasive wheel is the occurrence of tensile stresses of I-type during α-phase of structure of the high-speed release (Fig. 1, h). Their maximum value according to (σ1 + σ2) is achieved at a depth of 30-50 micron below the surface. During γ-phase small compressive stress takes place, extending to a depth of 40 micron.

Table 1*The amount of residual austenite, f_γ% in 107WCR5 steel after grinding by abrasive wheels and after turning by cutters of composite-10*

№	Type of processing	Depth, (mm)						
		10	20	30	40	80	120	160
		$f_{\gamma,}$ %						
1	Grinding by abrasive wheel	23	27	28	28	29	30	30
2	Turning by cutters of composite-10, 20 m/min	25	28	30	31	31	31	31
3	Turning by cutters of composite-10, 40 m/min	25	27	29	30	35	36	38
4	Turning by cutters of composite-10, 80 m/min	31	32	33	33	36	37	37
5	Turning by cutters of composite-10, 160 m/min	36	37	38	39	41	41	41
6	Turning by cutters of composite-10, 250 m/min	31	31	31	32	32	33	34

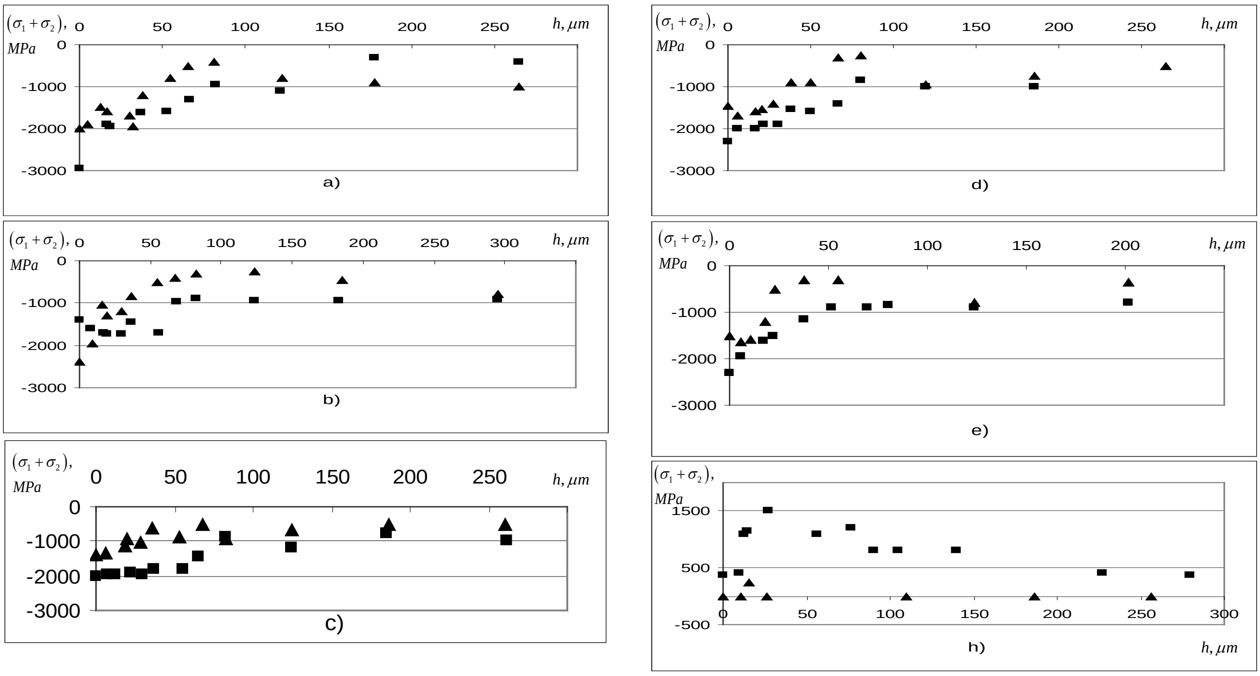

Fig. 1 *- Distribution of residual stresses of the first kind in depth of the surface layer at V = 20 (a); 80 (b); 160 (c); and 250 m/min (d), grinding with abrasive wheel (h), (■ –γ-phase, ▲– α-phase)*

For the fatigue test four batches of samples were made. First – machined by grinding wheel according to the following routine: RPM range - 2800 rotations/min, number of revolutions of the sample - 400 rev/min; second, third and fourth - composite-10 at a cutting speed V = 50, 100 and 200 m/min. respectively; depth of cut and delivery rate for the last three parties remained constant and equal to t = 0,25 mm S = 0,07 mm/rev. The results of fatigue testing of the above 107WCR5 steel batches of samples are presented in Fig. 2.

Data for stress-cycle diagram, correlation coefficients and limited fatigue strength are shown in Table 2. The analysis of the test results shows that, on the basis of approved testing, fatigue resistance of the material is characterized by a sloped fragment of a diagram – beginning of stress-cycle diagram is shifted towards longevity. The stress-cycle diagram of the fourth installment sample (200 m/min.) is located below the 2nd and 3rd parties curves and the limited endurance limit is 10% lower than for the 2nd batch.

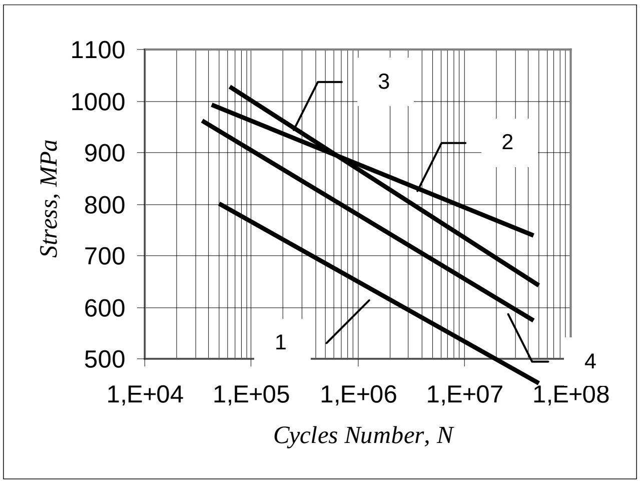

Fig. 2. *- Stress-cycle diagram of 107WCR5 steel samples: grinding with abrasive wheel - (1); turning with cutter of composite-10 at a speed V = 50 (2), 100 (3) and 200 (4), m/min.*

Table 2. *The results of fatigue tests of 107WCR5 steel samples in a cantilever bending*

№	Type of processing	Correlation coefficients		Limited fatigue strength σ_{-1}, MPa
		A	*M*	
1	Grinding by abrasive wheel	12,09	-0,0089	660
2	Turning by cutters of composite-10 R, 50 m/min	16,07	-0,01126	827
3	Turning by cutters of composite-10, 1000 m/min	12,76	-0,00776	770
4	Turning by cutters of composite-10, 200 m/min	12,27	-0,00775	735

Endurance of grinded test samples is significantly lower than endurance of samples turned with cutter of composite-10. Narrow endurance limit for the first batch (560 MPa) is by 32% lower than for the 2nd batch. This is due to the fact that in the process of cutting with composite-10 fast tempering in the surface layers of steel goes under stress, this causes compressive residual stress of the 1st type in α- and γ-phase, slowing the decay of residual austenite. The combination of evenly spaced brittle and ductile structural components in the surface layer enhances endurance of 107WCR5 steel. While grinding with abrasive wheel is causing tensile stresses of the 1st kind in the γ-phase, partially decomposes retained austenite and increases the degree of its hardening.

Conclusion. Thus, studies of the process of grinding with abrasive wheels and turning with cutters of composite-10 a tool steel alloy 107WCR5 showed the following:

- the increase of thermal conductivity of the tool material is narrowing the area of the structural changes occurred in the surface layer of the processed material, it is minimal for turning with cutters of composite-10;
- the amount of residual austenite in the process of turning with cutter of composite-10 is lowest within the limits of cutting speed 40-80 m/min;
- the joint effect of pressure and temperature in high-speed cutting reduces the degree of strain hardening γ- phase in the surface layer;
- machining by composite-10 tool for α- and γ-phases in the surface layer is only accompanied by compressive residual stresses, while grinding with abrasive wheels contributes to the tensile I-type stress in α-phase structure of tempering speed;
- turning by cutters of composite-10 increases on 30% the endurance limit, compared with the grinding by abrasive wheels, wherein the increasing of cutting speed from 50 to 200 m/min does not cause the substantial change of resistance to fatigue.

Literature

1. Ящерицин П. И. Теория резания. Физические и тепловые процессы в технологических системах / П.И. Ящерицын, М.Л. Еременко, Е.Э. Фельдштейн. Минск.: Вышейшаяшкола, 1990, 512 с.

2. Nizhnik S.B. Formation of secondary structures in steels at high pulsed temperature and pressureRussian metallurgy // Metally. 2006. T. 2006. № 4. C. 314-322.

3. Нижник С.Б. К вопросу формирования вторичных структур в сталях при импульсном действии высоких температур и давлений // Металлы. 2006. № 4. С. 42-53.

4. Обработка инструментом сталей резцами из Гексанита-Р / Г.Г. Карюк, М.С. Пивоваров, В.П. Барабан и др. // Гексанит и Гексанит-Р и изделия на их основе инструментального назначения.– Киев.ин-т пробл. материал. АН УССР, 1975.– С. 14-17.

5. Постнов, В. В. Процессы на контактных поверхностях, износ режущего инструмента и свойства обработанной поверхности / В. В. Постнов, Б. У. Шарипов, Jl. Ш. Шустер. Свердловск: Изд-во Уральского ун-та, 1988.-224 с.

6. Кагаев В.П., Дроздов Ю.Н. Прочность и износостойкость деталей машин.- М: Высшая школа, 1991, 320 с

7. Суслов, А. Г. Качество поверхностного слоя деталей машин Текст. / А. Г. Суслов. М.: Машиностроение, 2000.– 318 с

8. Сулима, А. М. Поверхностный слой и эксплуатационные свойства деталей машин / А. М. Сулима, В. А. Шулов, Ю. П. Ягодкин. М.: Машиностроение, 1988. - 238 с.

9. Терентьев В.Ф. Усталость металлических материалов, Изд-во: Наука, 2003, 257 с.

10. Приймачук В.Л., Божко А.В. Овенесян А.О. Теплофизические свойства разных модификаций нитрида бора // Порошковая металлургия.–1983.–№ 8.– . 80-82.

11. Волкогон В.М., Котляр Д.А., Аврамчук С.К., Кравчук А.В., Антонюк В.С. ВпливпопередньоїпідготовкипорошківBNв до спікання на основні характеристики процесуобробкисталі ШХ15 в режимібезперервногорізання // Високітехнологiї в машинобудуванні: Зб. науковыхпраць.- Харків НТУ «ХПІ», 2010- Вип. 1.- С. 35-44.