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To cite this article: S.V. Gruby *et al* 2016 *IOP Conf. Ser.: Mater. Sci. Eng.* **142** 012065

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Controlling the type and the form of chip when machining steel

S.V. Gruby¹, A.A. Lasukov^{2,1}, R.Yu. Nekrasov³ E.V. Politsinsky²
and D.A. Arkhipova²

¹Moscow State Technical University by N.E. Bauman, ul. Baumanskaya 2-ya, 5/1, Moscow, 105005

²Yurga Institute of Technology, TPU affiliate 26, Leningradskaya street, Yurga, 652050, Russia, tel.+ 7 38451 77761

³Tyumen State Oil and Gas University 38, Volodarskogo street, Tyumen, 625000, tel.+ 7 3452 4124 65

¹E-mail: lasukow@rambler.ru,

Abstract. The type of the chip produced in the process of machining influences many factors of production process. Controlling the type of chip when cutting metals is important for producing swarf chips and for easing its utilization as well as for protecting the machined surface, cutting tool and the worker. In the given work we provide the experimental data on machining structural steel with implanted tool. The authors show that it is possible to control the chip formation process to produce the required type of chip by selecting the material for machining the tool surface.

1.Introduction

The type of the chip influences many factors of production process. Development of high-speed machine tools, machines with increased capacity and strength, introduction of new tool materials lead to significant increase of machining efficiency and its productivity mainly due to increase of cutting speed. From the growth of the cutting speed the need arises for providing safe and rational chip removal. Controlling the type of chip when metal cutting is important for producing swarf chips and for easing its utilization as well as for protection of machined surface, cutting tool, worker, for reducing the energy input when machining materials [1]. With the development of automated machining operations the necessity of chip formation control increased significantly [2, 3]. The ability for controlling the chip formation process is also important in the process of machining the reconditioned machine parts [4]. The practice of structural materials machining has developed one of the most wide-spread methods – cutting with the tool which has a flute on the front surface or steps in the path of chip escape. They ensure satisfactory chip removal. The removed chip in this case is, as a rule, continuous. Machining of materials with the property of discontinuous chip formation is not a factor preventing from cutting and working at high speed. At the same production of special elements for the tool arises certain difficulties and leads to the tool cost increase.

Producing discontinuous chip when machining eases its removal from the cutting area which is especially important when operating automated machines. Zelinsky A.N. [5] notes that cutting with discontinuous chip formation is related to increasing tool wear resistance.



Study of chip formation is the most efficient and inexpensive method to understand the characteristics of materials machining.

According to research works by Kufarev G.L. [6] to ensure chip control the following conditions should be observed: producing chip which is tough enough; curling of the chip due to inhomogeneity of deformation in various layers of metal; directing the flow of chip towards natural obstacle which curves the chip in the opposite direction to curling. Discontinuous chips are usually tough, with varied strength and have weak longitudinal bonds in the areas of deformation. curling of these chips is achieved due to the difference of speeds of separate layers of metal in the plastic domain of chip formation area. The chip flow direction to curve it as needed can be changed by changing (shortening) the radius of curvature of the chip.

Obtaining of necessary form and type of chip strongly depends upon the contact relations at the front surface of the tool. It is obvious that those phenomena are associated with adhesive behavior of machined and tool materials.

The increased adhesive capability of the contacting materials leads to the growth of friction at the front surface. And this results, as has been shown above, in changing of the force of interaction between the materials and formation of continuous chips. Behavior of metals under friction depends upon their mutual solid-phase solubility and ability of forming chemical compounds with each other. Thus, the main factor determining the friction behavior at the front surface is the ability of metals to form solid solutions and intermetallic compounds. That means that the chemical properties of machined materials which determine their mutual solid-phase solubility have the determining influence upon the friction behavior.

If we know under which conditions the continuous chip changes into discontinuous one we can control the chip type without adding special elements to the instrument, thus, making it cheaper [6]. We can control the chip type by changing the properties of the front surface of the tool to change the surface conditions. One of the ways of solving the given problem is ion implantation of the tool with ions of various materials. This, in its turn, leads to significant increase of tool wear resistance when machining titanium, heat-resistant and corrosion-resistant alloys usually associated with severe wear of the tool.

Changing the properties of the front surface of the tool [8, 9] we can control the process of chip formation through transformation of its basic characteristics: contact length, friction ratio, cutting forces, shearing angle, etc. Ion implantation of the cutting tool changes the adhesive contact between the chip and the tool. This leads to changes in the character of chip formation increasing chip fragility in most cases which eases its breaking and removing from the cutting area. Other ways of high-speed steel tool impacting are shown in [10], treatment of inserts with pulsed electron beam is considered in [16].

Choice of material for implantation should be made according to the condition of maximum reduction of probability of seizure between the machined material and the tool.

According to the said above we can make the conclusion that it is possible to control the process of chip formation achieving its required form and type, through changing the characteristics of the front surface. Considering that ion implantation influences the tool efficiency together with changing the chip formation character it is worth applying tools with modified surface for machining.

2. Methods of experimental study

In the given work we provide experimental data on machining structure 30HGSA steel with ion implanted tool. Inserts having quadrihedral shape from carbide alloy T5K10 were used as tool material. Implantation was completed on ION-700 with the following materials: Al, BN, TiB₂, ZrGf and Zr. Besides we applied inserts with TiN coating which were additionally implanted with various materials.

The workpiece was machined at the CNC screw-cutting lathe 16K20F3C32 under the constant supply $S=0.21\text{mm/rev}$ and cutting depth $t=2\text{mm}$. The cutting speed changed within rather wide range $V=50\dots200\text{ m/min}$. Changing of the cutting force and chip formation characteristics were registered at the same time.

3. Results and Discussion
























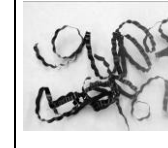


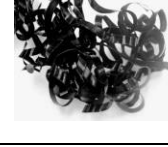

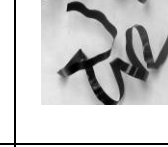






As the experimental data on structure steel machining show the chip formation is rather sensitive to the changes of tool surface properties.

Machining with unimplanted tool within the whole range of cutting conditions leads to formation of continuous chip which enmeshes significantly. Such chip is inconvenient in terms of safe work and, being accumulated in the working area, it disturbs normal work of equipment. Besides this type of chip flows down the machined surface deteriorating its quality [11]. Winding of the chip around the tool may lead to its loss of function. Holding-up to remove this chip leads to equipment downtime and, thus, to productivity reduction. Machining with this kind of tool is associated with high cutting force values which tells upon wear resistance of the tool leading to its deterioration.

In Tables 1 and 2 we present the changes of the chip and its edge according to the change of cutting speed and type of the modified surface.

Changing of chip appearance

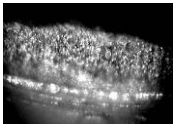
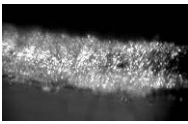
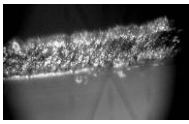
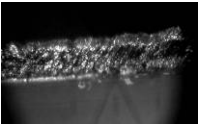
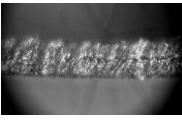
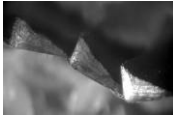



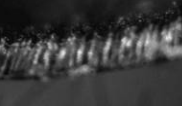
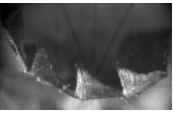

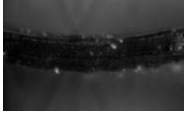
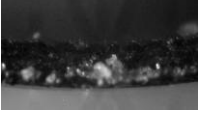
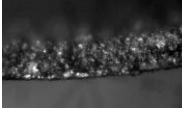

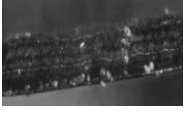

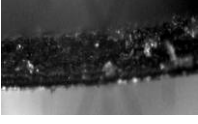
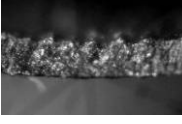
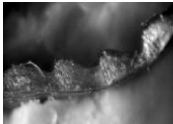

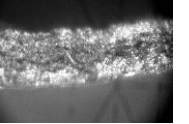
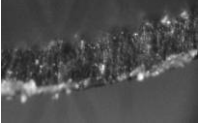
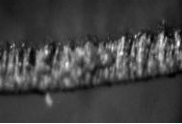

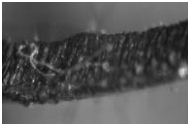
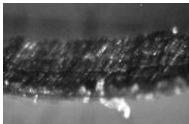
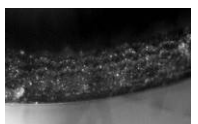
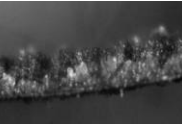


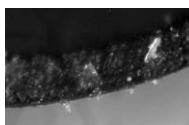

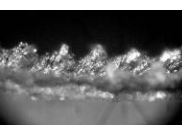
Table 1

Implanted material	Speed of cutting, m/min.				
	50	80	126	159	202
T5K10 (basic)					
Al					
TiB ₂					
Zr					
Al with coating					
TiB ₂ with coating					
ZrGf with coating					

Analysis of the cutting process characteristics showed the changes of the cutting forces, chip shrinkage and shearing angle when machining under the described conditions. It is interesting to note that implantation of the instrument by any of materials applied in our experiments leads to reduction of the cutting force, chip shrinkage and increase of the shearing angle. All that results in more favorable conditions for machining steel as well as in reduction of power consumption when cutting [12].

Chip edge

Table 2

Implanted material	Cutting speed, m/min.				
	50	80	126	159	202
T5K10 (basic)					
Al					
TiB ₂					
Zr					
Al with coating					
TiB ₂ with coating					
ZrGf with coating					

It should be noted that tool coated with TiN and additionally implanted with TiB₂ does not practically impact the process of chip formation when machining 30HGSA steel. As one can see from the presented photographs the form of the chip changes very little, the edge of the chip does not change very much either. At the same time the main component of the cutting force intensively decreases

within the studied range of cutting speeds. The shearing angle is large but stays practically unchanged within the studied range of the cutting speeds during the process of machining. Chip shrinkage is low and with the growth of cutting speed changes insignificantly.

When implanting the tool with other materials the chip from being obviously discontinuous under low cutting speeds changes to continuous as the cutting speed grows. The appearance of the chip shows that with speed growth the discontinuous "bit-like" chip turns into tapes and in some cases forms coils which are hard to remove from the cutting zone. This type of chip is difficult to work with under speeds applied in production.

The properties of the tool surface impact chip formation in a different way even if the tool is implanted with similar material. From Table 1 we can see that machining with the tool implanted with aluminum (Al) the chip turns into tapes with the growth of cutting speed. The chip produced in the process of machining with previously applied coating (titanium nitride – TiN) and implanted ions (Al) was continuous under low speeds (the ripples on the edge were not seen) and remains the same, at the first glance, under high-speed cutting. But even a small effort makes it crush into pieces. Thus, the properties of coating together with those of implanted material reduce the forces at the front surface, namely the force of friction, and it leads to formation of such chip.

Machining of steel with TiN-coated inserts implanted with ZrHf ions (20% hafnium) is of practical interest. When machining with tool of this kind we observe a reversed pattern of chip formation. As speed grows the chip becomes discontinuous. As it is shown in Table 1 chip produced under the cutting speeds close to those applied at factories (speed of approximately 200 m/min) crushes into separate elements. Such chip is convenient for removing, transportation and recycling. Analysis of the cutting force changes showed that the main component of the cutting force becomes significantly smaller (by up to 300 – 350 N) in comparison to that when cutting with unimplanted tool. The values of the cutting force also appeared to be lower in comparison to those when cutting with the tool implanted with other materials. Chip shrinkage under cutting with such tool is low and does not change significantly with the change of cutting speed. It indicates that the deformation degree decreases when machining with such tool resulting in reduction of cutter load and improving tool efficiency.

These phenomena can be explained by the change of adhesive properties on the front surface of the cutter. When we work with the tool implanted by different materials the force of adhesion of chip and tool surfaces is different. Similar phenomena are observed when coating machine parts [13]. Adhesion causes stagnation: at some part of the contact area adhesion between different metallic surfaces (chip-cutter) becomes larger than slip resistance of the contact layer of the chip, the thin layer slows down and further sliding occurs inside the chip. The given layer, evidently, prevents the chip from finally breaking into pieces under high-speed cutting. Intensity of adhesion is mainly determined by the ability of the contacting metals for mutual solution [14].

The characteristics of such interaction of the tool implanted with ZrHf ions can be supposedly explained by little interaction of these elements with iron. The adhesion at the front surface reduces, so does the cutting force, the chip becomes discontinuous. This points to the fact that the degree of deformation varies depending upon the properties of tool surface.

In work [15] the authors analyze the resultant of the cutting force and the radial stresses in the tool. The value of the resulting force in all cases of working with implanted tool is smaller than that when working with usual tool. The value of the resulting force is the smallest when working with TiN+ZrHf coated tool. The authors also establish reduction of stresses when working with implanted tool. According to the authors the stresses in the tool are reduced due to reduction of the resultant of the cutting force and reduction of the angle between the resultant of the forces and the bisector of the angle of wedge ψ .

When working with TiB₂ implanted tool the given angle [15] increases within the whole range of cutting conditions under study. It is associated with low values of forces in the horizontal plane. When working with TiN+ZrHf coated tool the given angle reduces and has rather low values. The resultant approaches the bisector of the cutting edge angle. The photographs of the chips show that under tool implantation with TiB₂ the chips become matted as speed of cutting grows. If the tool is treated with

TiN+ZrHf the chip turns into its discontinuous form as the speed grows and becomes convenient for removing from the cutting zone.

4. Conclusion

The research shows that ion implantation of the cutting tool evidently leads to change of the tool resistance and of machined surface quality. Thus, we can say that it is possible to control the process of chip formation, improve tool efficiency, reduce energy input, ensure safe chip removal from the cutting zone through changing the properties of tool surface with ion implantation.

Analysis of experimental data allows recommending application of T5K19 carbide alloy inserts with TiN coating implanted with ZrHf ions (20% hafnium) for producing discontinuous chip in the process of 30HGSA steel machining at automated lines and CNC tools without implementing additional elements for chip crushing.

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