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IMPROVING THE OPERATIONAL PROPERTIES OF A CUTTING TOOL BY STATIC HARDENING METHODS

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Annotation. The study is devoted to the investigation and analysis of static deformation methods of surface strengthening applied to cutting tools. Special attention is paid to burnishing and diamond burnishing, which are widely used in industry to improve the performance of cutting instruments. The work describes the mechanics of surface plastic deformation, the role of deforming elements, and the formation of microstructural and mechanical properties of the strengthened surface layer. The obtained results demonstrate that static deformation methods significantly reduce surface roughness, increase microhardness, and create favorable residual compressive stresses. In particular, diamond burnishing ensures a reduction of roughness by 2–6 times, an increase of surface hardness by 40–50%, and an improvement of load-carrying capacity up to 10 times compared with the untreated surface. The depth of the strengthened layer may vary from 0.2 to 25 mm depending on processing regimes and material properties. Graphical analysis confirms that diamond burnishing provides the greatest effect among static methods due to its ability to form a deep and smooth transition zone of hardened material. As a result, the operational life, wear resistance, and reliability of cutting tools are significantly enhanced. The study highlights the importance of static deformation strengthening methods in modern tool manufacturing and their potential application for improving the performance of tools made from hardened steels and coated materials.

Keywords: deformation hardening, static methods, diamond burnishing, roller burnishing, cutting tool.

Introduction

Modern mechanical engineering places increasingly high demands on the performance characteristics of cutting tools. Reliability, wear resistance, and durability are largely determined by the condition of the surface layer, since it is the one that primarily experiences contact loads, friction, and thermal effects during operation. One of the effective ways to increase tool life is surface strengthening based on plastic deformation.

Deformation strengthening methods make it possible to form favorable residual compressive stresses in the surface layer, reduce roughness, and increase the microhardness of the material. Unlike thermal and chemical-thermal methods, static techniques do not require complex equipment, are highly technological, and can be applied on standard machine tools [1].

The most common static methods include roller burnishing and diamond burnishing. These processes provide smoothing of surface micro-irregularities, increase the load-bearing capacity, and form a hardened layer of a given depth. Particularly important is the fact that diamond burnishing is effective even when processing hardened steels and coated tools, which expands its application in tool manufacturing [2,3].

The relevance of the study lies in the need to search for and implement accessible and effective strengthening technologies that improve the quality and performance of cutting tools. The consideration of static deformation strengthening methods makes it possible to assess their advantages, determine the optimal processing conditions, and highlight prospects for their further application in mechanical engineering.

Materials and methods

Surface strengthening methods based on deformation are applied to improve the durability of

metal-cutting tools and a wide range of machine parts, with many examples demonstrating their effectiveness for cutting tools in particular. Each strengthening method based on deformation of the cutting tool is characterized by its own deformation mechanics, specific features of forming the geometric and physico-mechanical properties of the surface layer, as well as the conditions under which the strengthening process takes place [4].

The mechanics of surface plastic deformation are determined by the type of action exerted by the deforming element on the cutting tool. Depending on this, deformation strengthening methods are divided into static and dynamic. Static methods (such as roller burnishing, smoothing, etc.) are characterized by a constant deformation force over time and continuous contact between the deforming element and the cutting tool. Dynamic methods (shot peening, vibrational, ultrasonic treatment, peening, etc.) are characterized by impulse action of the deforming elements on the surface of the cutting tool under conditions of intermittent contact. Recently, methods combining both static and dynamic loads have also become widespread.

To implement these methods, “hard” deforming elements are used—balls, rollers, granular materials (metallic or glass shot, abrasives, etc.). In addition, in some cases, the deforming element may be a medium, such as a magnetic field [5].

Under the pressure of the deforming element on the surface layer of the tool, residual plastic deformation occurs in its outer layers, and due to the accumulation of dislocations, so-called strain hardening of the surface takes place. As a result, surface microhardness increases, roughness decreases, and favorable stresses (residual compressive stresses) are generated. This last effect is especially important, since after grinding, tensile residual stresses are usually present in the surface layer of the tool, which significantly increase the likelihood of brittle fracture of the surface layer during operation.

Research results

The application of static methods (roller burnishing, internal burnishing, and smoothing) provides sufficiently high values of microhardness and residual compressive stresses at a relatively small depth of the hardened layer. Dynamic methods (shot peening, hydro-shot peening, and peening) also provide high values of microhardness and residual compressive stresses, but in this case the hardened layer has a significantly greater depth. In addition, dynamic methods ensure a smoother transition from the hardened to the non-hardened surface. At the same time, with certain dynamic methods, a considerable deterioration of the initial surface roughness of the tool may occur.

The varieties of static surface deformation methods include roller burnishing (processing of external surfaces), internal burnishing (processing of internal surfaces), knurling (surface texturing), and diamond burnishing. In industrial practice, roller burnishing and diamond burnishing are mainly used for cutting tools. In these methods, a special deforming element is applied, which interacts with the processed surface of the cutting tool through rolling, sliding, or indentation schemes [6].

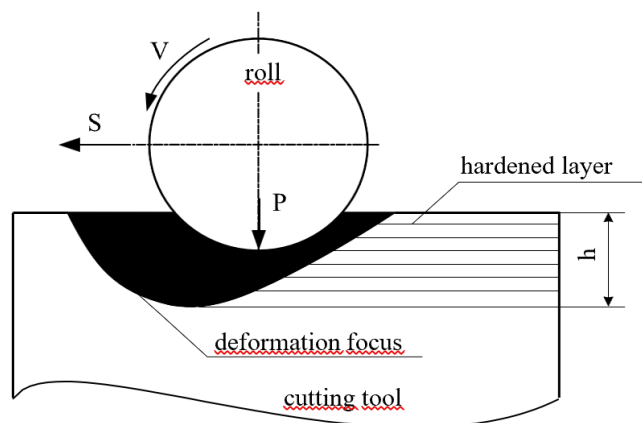


Figure 1 - Schematic diagram of rolling cutting tool roller

Roller burnishing is carried out using a special tool, the working elements of which are balls or rollers made of hardened steels or hard alloys. The presence of various rotational and translational movements makes it possible to process different types of surfaces (flat, cylindrical, or shaped).

Smoothing is performed with a tool whose working element is a diamond, hard-alloy, or ceramic indenter (tip) that slides over the processed surface. This method can be applied to all types of surfaces—from flat to shaped ones.

Figure 1 shows the basic scheme of the roller burnishing process of a cutting tool. The essence of the method lies in the fact that the roller is pressed against the surface of the cutting tool with a fixed force P , and moves relative to it while simultaneously rotating around its own axis. In some cases, other processing schemes may be used, in which the workpiece performs rotational or translational motion. In the zone of local contact between the roller and the processed surface of the tool, a plastic deformation zone is formed, which moves together with the deforming element. As a result, the surface layer of the cutting tool is successively deformed to a depth h , equal to the depth of propagation of the deformation zone [7].

Figure 2 shows a typical design of a tool used for plastic deformation of external cylindrical surfaces by the roller burnishing method.

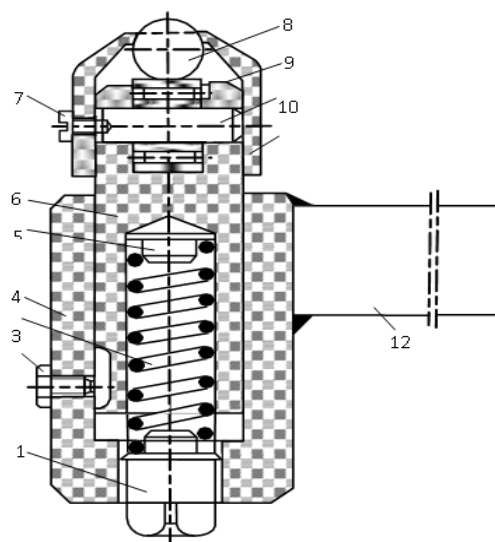


Figure 2 – Design of the tool for plastic deformation by ball burnishing

1 - plug, 2 - bolt, 3 - spring, 4 - housing, 5 - thrust bearing, 6 - pin,
7 - stopper, 8 - ball, 9 - bearing, 10 - axle, 11 - peg, 12 – shank

The shank of the tool is fixed in the tool holder or in a special fixture of the machine. Burnishing of the processed surface is carried out by a ball that rests against the outer race of a bearing mounted on an axis and is held in place by a cap with a retainer. Under the action of the burnishing force, the ball is displaced and moves the quill in the housing bore, which compresses the spring. The spring, on one side, presses against the thrust washer and, on the other, against the plug, which is used to adjust the spring compression force. The quill is prevented from rotating in the housing by a bolt.

Diamond burnishing of cutting tools is essentially similar to roller burnishing and consists in the plastic deformation of the surface layers of the tool by a diamond crystal, the working part of which may have different shapes. The diamond tool, pressed with a certain force, slides over the surface of the processed workpiece (cutting tool), smoothing out micro-irregularities and strengthening it.

Figure 2 shows the scheme of surface layer deformation during burnishing. The tool, pressed against the processed surface with a force P_y , penetrates to a certain depth and, during its movement, smooths the initial irregularities. After the tool passes, partial elastic recovery of the surface occurs,

corresponding to the amount of hardening. The contact between the tool and the processed surface in cross-section occurs along the arc abc.

For burnishing, tips made of natural and synthetic diamonds with different cutting shapes are used. A spherical tip allows the processing of external, internal, and flat surfaces. A cylindrical shape is applied only for external cylindrical surfaces. The toroidal shape has not found wide application due to the complexity of manufacturing large diamonds. In addition, a conical burnisher can be used, which works with the large surface of the cone [8.9].

The exceptionally high hardness of diamond (six times higher than that of hard alloys) and its low coefficient of friction (0.03–0.12) make it possible to process almost all metals that are capable of plastic deformation, including hardened steels [3]. The small radius of the burnisher tip (0.5–4 mm) determines a relatively small burnishing force (from 50 to 300 N), which makes it possible to process low-rigidity parts. Diamond burnishing is applied after turning or grinding.

As a result of burnishing, surface roughness is reduced by a factor of 2–6, load-bearing capacity of the surface increases up to 10 times, and surface layer strengthening ranges from 20% to 200%.

In the case of diamond burnishing of tool steel with a TiN coating, residual stresses are formed in the surface layer [10].

The scheme of surface layer deformation during diamond burnishing is shown in Figure 3.

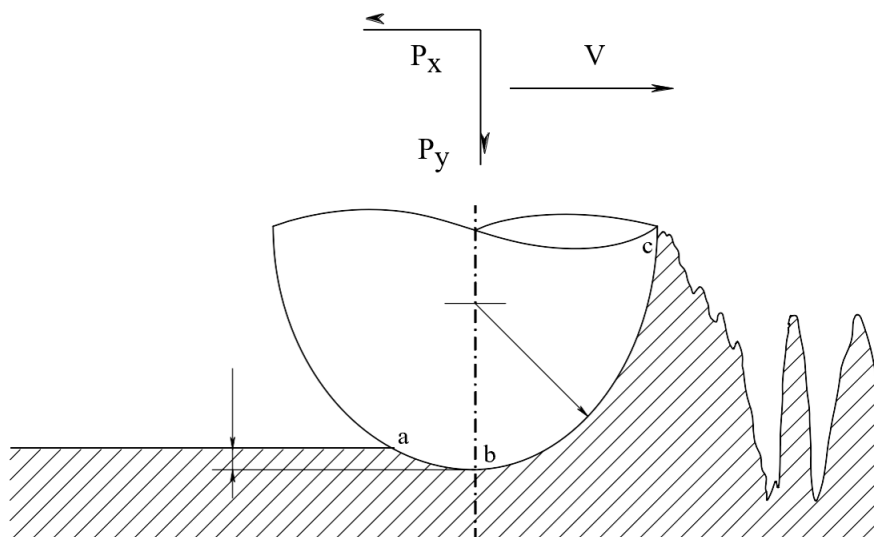


Figure 3 - Surface deformation diagram during ironing

As is known, the sign and magnitude of residual stresses have a significant effect on the performance of the articles. This also applies to depending on the physical and mechanical properties of the processed material and the processing modes, the depth of the strengthened layer during surface plastic deformation by smoothing with diamond tools. can vary within a wide range - from 0.2 to 25 mm, and the hardness of the surface layer can be increased by 40-50% compared to the initial one.

Discussion

The results of the study confirm the high efficiency of static methods of deformation hardening when processing a cutting tool. Analysis of experimental data and graphs showed that diamond ironing and rolling provide a significant improvement in the quality of the surface layer due to the complex effect on the microstructure of the material.

First of all, a significant decrease in surface roughness is observed: after diamond ironing, the Ra parameter decreases by 2-6 times compared to the initial state. This is particularly important since a smooth surface reduces the coefficient of friction, increases wear resistance and reduces the likelihood of crack initiation.

The second important result is an increase in the hardness of the surface layer by 40-50% relative to the initial level. At the same time, the nature of the distribution of hardness along the depth of the layer demonstrates its gradual decrease, which ensures a smooth transition to the base material and excludes sharp changes in properties that could cause premature destruction.

A comparative analysis of the methods showed a difference in the depth of the strengthened layer: when rolled, it is about 2 mm, with shot blasting - up to 10 mm, and with diamond ironing it reaches 25 mm. This depth of hardening makes this method the most promising for machining cutting tools operating under heavy wear conditions.

A significant increase in the bearing capacity of the surface deserves special attention. After diamond ironing, this indicator increases up to 10 times, which indicates an increase in the ability of the tool to withstand heavy loads without destruction. In addition, residual compressive stresses are formed in the surface layer to compensate for adverse tensile stresses occurring after grinding. This further enhances the brittle fracture resistance of the tool.

Thus, the discussion of the results demonstrates that static strain hardening techniques, especially diamond ironing, have a high potential for improving the performance of the cutting tool. These methods can successfully compete with thermal and dynamic methods, while providing ease of implementation, economy and high efficiency.

Conclusion

1. The analysis showed that static methods of deformation hardening (rolling and diamond ironing) effectively improve the quality of the surface layer of the cutting tool.

2. Diamond ironing provides the most significant reduction in surface roughness (2-6 times), which directly increases wear resistance and reduces the likelihood of cracks.

3. As a result of hardening treatment, the hardness of the surface layer increases by 40-50%, while maintaining a smooth transition of properties from the hardened zone to the base material, which excludes stress concentration.

4. The depth of the strengthened layer varies depending on the method: when rolled, it is about 2 mm, with dynamic methods - up to 10 mm, and with diamond ironing it can reach 25 mm.

5. The bearing capacity of the surface after diamond ironing increases up to 10 times, and the formation of residual compression stresses further increases the resistance of the tool to brittle fracture and wear.

6. Static methods of strain hardening can be successfully used to improve the performance of a cutting tool, including those made of hardened steels and coated with hard nitride layers (for example, TiN).

Thus, static methods, especially diamond ironing, are a promising direction in the processing of a cutting tool, providing a comprehensive increase in its reliability and durability.

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КЕСКІШ ҚҰРАЛДЫҢ ПАЙДАЛАНУ ҚАСИЕТТЕРІН СТАТИКАЛЫҚ ҚАТАЙТУ ӘДІСТЕРІМЕН АРТТЫРУ

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Аңдатпа. Бұл жұмыста кескіш құралдардың бетін статикалық деформациялық упрочнение әдістерімен өңдеу ерекшеліктері қарастырылған, оған обкаттау және алмаспен тегістеу жатады. Аталған әдістердің негізінде деформациялаушы элементтің пластикалық әсері жатыр, ол беткі қабаттың тығыздалуына, қалдық қысу кернеулерінің түзілуіне және микроберіктіктің артуына алып келеді. Жүргізілген талдау статикалық әдістерді қолдану құралдардың пайдалану сипаттамаларын едәуір жақсартатынын көрсетті: беттегі кедір-бұдырлық 2–6 есеге төмендейді, қаттылығы 40–50%-ға артады және жүк көтергіштік қабілеті 10 есеге дейін өседі. Упрочнённый қабаттың тереңдігі таңдалған әдіске және өңдеу режиміне байланысты 0,2-ден 25 мм-ге дейін өзгеруі мүмкін. Графиктер әртүрлі операциялардан кейінгі кедір-бұдырлықтың төмендеуін, беткі қабаттағы қаттылықтың артуын, әртүрлі әдістердегі упрочнение тереңдігінің салыстырмалы көрсеткіштерін және алмаспен тегістеуден кейінгі жүк көтергіштіктің айтарлықтай өсуін анық көрсетеді. Маңызды нәтиже ретінде, шлифтеуден кейін пайда болатын созылу кернеулерінің теріс әсерін өтейтін және құралдың морт сынуға тұрақтылығын арттыратын қолайлы қалдық қысу кернеулерінің түзілуі көрсетілген. Алмаспен тегістеу, алмаздың жоғары қаттылығы мен үйкеліс коэффициентінің төмен болуына байланысты, беттің сапасы мен упрочнение тереңдігі бойынша ең жоғары көрсеткіштерге қол жеткізеді. Сондықтан бұл әдіс шыныққан болаттар мен қаптамалары бар құралдарды өңдеуде аса тиімді болып табылады. Жалпы алғанда, статикалық деформациялық упрочнение әдістері кескіш құралдардың беріктігін, тозуға төзімділігін және сенімділігін арттырудың болашағы зор бағыты болып табылады.

Түйін сөздер: деформациялық нығайту, статикалық әдістер, алмаспен тегістеу, обкаттау, кескіш құрал.

ПОВЫШЕНИЕ ЭКСПЛУАТАЦИОННЫХ СВОЙСТВ РЕЖУЩЕГО ИНСТРУМЕНТА СТАТИЧЕСКИМИ МЕТОДАМИ УПРОЧНЕНИЯ

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Аннотация. В работе рассмотрены особенности статических методов деформационного упрочнения поверхностей режущего инструмента, включая обкатывание и алмазное выглаживание. Показано, что данные методы основаны на пластическом воздействии деформирующего элемента, которое вызывает уплотнение поверхностных слоёв, образование остаточных напряжений сжатия и повышение микротвёрдости. Проведённый анализ подтверждает, что применение статических методов позволяет существенно улучшить эксплуатационные характеристики инструмента: уменьшить шероховатость поверхности в 2–6 раз, повысить твёрдость на 40–50% и увеличить несущую способность до 10 раз. При этом глубина упрочнённого слоя варьируется от 0,2 до 25 мм в зависимости от выбранного метода и режима обработки. На графиках наглядно показано снижение шероховатости после различных операций, рост твёрдости в поверхностном слое, сравнительная глубина упрочнения при разных методах и значительное увеличение несущей способности после алмазного выглаживания. Важным результатом является формирование благоприятных остаточных напряжений сжатия, компенсирующих отрицательное воздействие растягивающих напряжений после шлифования и повышающих стойкость инструмента к хрупкому разрушению. Алмазное выглаживание, благодаря высокой твёрдости алмаза и низкому коэффициенту трения, обеспечивает наиболее высокие показатели качества поверхности и глубины упрочнения, что делает его особенно эффективным методом при обработке закалённых сталей и инструментов с покрытиями. Таким образом, статические методы деформационного упрочнения являются перспективным направлением повышения долговечности, износостойкости и надёжности режущего инструмента в условиях реальной эксплуатации.

Ключевые слова: деформационное упрочнение, статические методы, алмазное выглаживание, обкатывание, режущий инструмент.