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Prospects of application of modern wear-resistant coatings to improve the performance properties of combined cutting and forming tools for finishing of cylindrical gears

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Abstract. The article deals with the aspects of improving the performance of a combined cutting and deforming tool designed for finishing gear machining of cylindrical gears. Presented are currently relevant proposals on the prospects for the applicability of wear-resistant coatings for this type of tool. It is emphasized that regardless of where coatings are used, they all have one thing in common: the coating changes the surface properties of the tool.

1 Introduction

Over the last decades, Tula State University has paid serious attention to the aspects of high-performance resource-saving processes of combined (cutting and deforming) finishing and finishing of cylindrical gears. In numerous works of Professors Valikov E.N., Yamnikov A.S., Boriskin O.I. and their students, in particular [1], high efficiency of shaving-rolling process for the finishing stage of gear machining is noted while ensuring consistently high accuracy and quality parameters of gears, processed by gear-rolling.

To implement the process under consideration, in conditions of production with a large output, it is required to use special tools – shave-rollers, the designs of which are calculated and designed individually for each gear [2]. Due to the complex configuration of the cutting elements and rather large weight and size parameters (overall diameter da up to 250 mm, weight m up to 3 kg), shave-rollers are usually made of high-speed steel. Since the shave-roller is an expensive and difficult to manufacture tool, it is obvious that serious attention should be paid to aspects of its design, manufacture and operation. In particular, one of the most important technical and economic characteristics that determine the effectiveness of the use of such a tool is the resource of its work.

For the front surfaces (FS) of the tool (Figure 1), wear is manifested by the formation of holes and an unacceptable change in geometry, while the cutting edges (CE), as they become dull, can "humble" inside the chip groove and even partially chip off in the absence of timely regrinding; for rear surfaces (RS) - dimensional wear is the most important parameter that has a significant impact on both the accuracy and quality of processing, and the service life

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of the tool, since its regrinding along these surfaces is impossible. In the process of tool wear, there is an excessive thinning of the side surfaces of its teeth, a distortion of their profile, which leads to a significant deterioration in the accuracy and quality of processing.

The wear of the front surfaces (FS) and, especially, the RS leads to an increase in the forces [3,4] acting in the tool-workpiece pair, an increase in the proportion of surface plastic deformation in the process of shave rolling, the appearance of excessive work hardening on the side surfaces of the teeth processed by cylindrical gear, deterioration in the accuracy and quality of processing. Dimensional wear of the rear surfaces (RS), which causes uneven thinning of the tool teeth, leads to an unacceptable decrease in accuracy in the process of combined gear cutting. Therefore, for the eighth degree of accuracy (GOST 1643-81) of crowns processed by cylindrical gear, the permissible deviation of the involute profile of the side surfaces of the tool teeth should not exceed 0.04 mm per side [5,6].

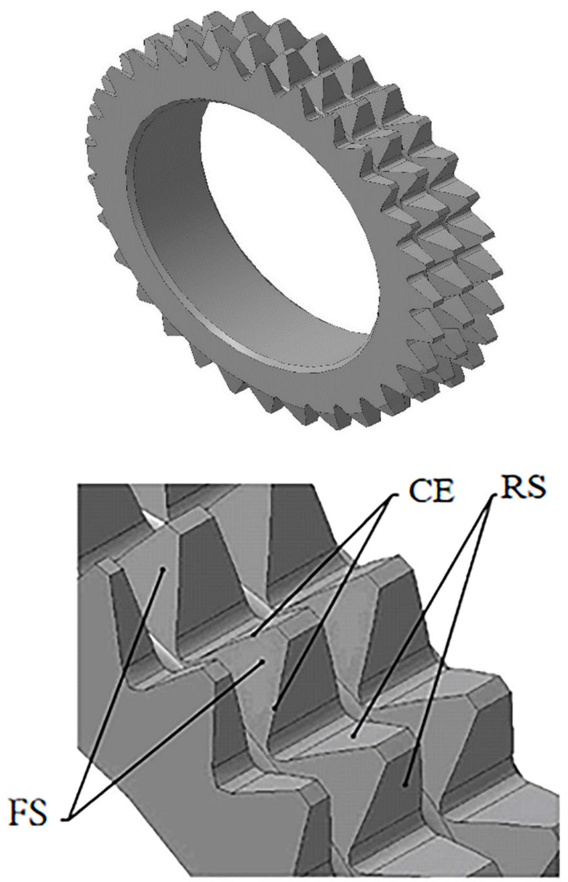


Fig. 1. Solid model of a shave-roller for gear-cutting of a cylindrical gear with selection of elements of cutting teeth.

In some value judgments were given about the period of durability of the tool in question. However, the results of specific resistance tests were not given. At the same time, the works note the impossibility of regrinding the tool along the back surfaces - the lateral involute surfaces of the cutting teeth and the usefulness of introducing measures to ensure their protection against premature wear: applying wear-resistant, including multilayer, coatings from the gas phase.

2 Materials and methods

Careful selection of the protective coating of the combination tool allows you to increase its service life, as well as improve the accuracy and quality of processing. A rather difficult scientific and technical problem is the choice of the optimal coating. During the operation of the tool, all types of coating have both advantages and disadvantages. Sometimes tool life is reduced due to the wrong coating, and the wrong coating can lead to more problems than positive results.

The industry uses a wide variety of PVD (Physical Vapor Deposition), CVD (Chemical Vapor Deposition) coatings, as well as a number of alternative surface hardening methods. The above processes play an important role in determining the optimal type of coating.

Currently, physical vapor deposition is the most commonly used method of applying protective coatings to cutting tools in production. When using the technology of deposition from the gas phase in production, it is necessary to have expensive high-purity chemical reagents (TiCl4, NH3, etc.) and precise control of chemical reaction products in the working chamber. In turn, this process has a higher productivity and is not so sensitive to minor deviations in technological parameters when applying PVD coatings using an arc or glow discharge (magnetron sputtering). Thus, the whole variety of methods of physical deposition of wear-resistant coatings is reduced to the evaporation or ion sputtering of titanium or its alloys with deposition on the working surfaces of tools.

Parameters such as: the degree of ionization, the speed and density of the sprayed particles, the optimization of the coating deposition temperature, various deposition modes, the configuration of technological equipment, the conduct of preliminary ion etching or alloying, and many other features determine the structure of the coatings themselves and the structure of the “coating-base” interface, and also determine the structure and adhesion of the tool coating, and its cutting properties.

The main characteristics of coatings can be considered:

1. Hardness. A high surface hardness of a coating is one of the best ways to increase tool life. Titanium carbonitride (TiCN) has a higher surface hardness than titanium nitride (TiN). The addition of carbon gives TiCN a 33% higher hardness, which in quantitative terms increases from 3000 to 4000 Vickers. The surface hardness in this case reaches 9.000 units.
2. Wear resistance. This is the ability of the coating to protect the working surfaces of the tool from abrasion. There are methods for increasing the wear resistance of a tool based on applying a special wear-resistant coating to its working surfaces. At the same time, the wear resistance of a combined tool without a coating can be much lower than that of a tool with a wear-resistant coating.
3. Surface lubrication. A high coefficient of friction, increased heat generation in the working zone of contact of the combined tool and the workpiece being processed leads to a decrease in its service life. However, a lower coefficient of friction can significantly increase this life. The amount of heat removed to the body of the tool can be reduced by modifying the surface layer, which acquires a small roughness. This smooth surface allows the workpiece material to slide off the tool surface, which in turn leads to less heat generation.
4. Increasing temperature resistance due to coating with titanium aluminum nitride. TiAlN coatings retain their hardness at higher operating temperatures due to the aluminum oxide layer that forms between the tool body and the cut layer. This layer prevents heat transfer from the cutting zone to the tool body. Titanium aluminum nitride coated tools typically run at higher speeds than conventional titanium nitride coated tools. The classic measuring tool is particularly coated with this type of coating using the PVD method.

The main types of prospective coatings:

1. Titanium nitride (TiN). General purpose PVD coating that increases hardness and has a high oxidation temperature. This coating works well on high-speed steel tools, which include the combined tool we are considering.
2. Titanium carbonitride (TiCN). The addition of carbon adds more hardness and improves surface lubricity. This coating is ideal for tools made of high speed steel.
3. Titanium aluminum nitride (TiAlN or AlTiN). The resulting layer of aluminum oxide gives this tool a longer service life at high temperatures. This coating is primarily selected for wet carbide tools. AlTiN offers higher surface hardness than TiAlN.
4. Diamond coating. Tool with CVD processing ensures maximum productivity. Ideal for graphite, metal matrix composites, high silicon aluminum and many other abrasive materials. Do not use diamond coatings when machining steels. Therefore, this kind of coating is not suitable for the tool we are considering. Since more heat is released during the processing of steels, causing chemical reactions that destroy the bonds that hold this tool coating.

3 Results and discussion

Thus, promising coatings for combined tools also differ in properties. Multi-layer coatings can also be recommended, which adhere to the next layer instead of the base material, providing a further increase in tool life.

In any case, such coatings have a thickness δ that varies within 7 μm. Therefore, for adequate operation of the tool, when designing it, it is necessary to take into account that its tooth (according to the base material) must be reduced by 2δ. This is illustrated by the diagram in Figure 2.

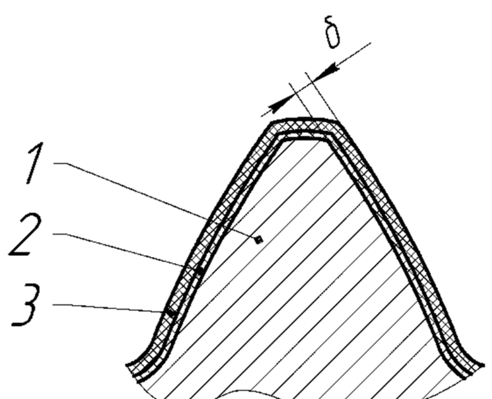
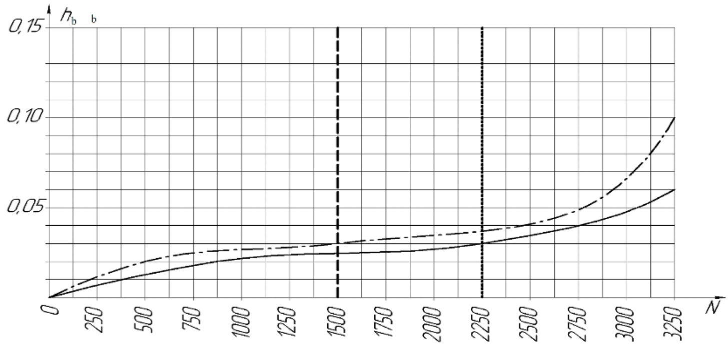


Fig. 2. The scheme of applying a wear-resistant coating to a tooth tool: 1 - base - high-speed steel; 2 - adhesive layer; 3 - protective layer

Combined gear cutting modes and cutting fluids (coolants) used can also influence the choice of coating. It should be noted that coating manufacturers are constantly working on new solutions that provide additional heat resistance of the tool and protection against friction and abrasion [7,8].

Based on the results of previous studies, in particular, the character of tool wear along the flank surface was established (Figure 3). The key factor in the wear of tools of the considered design is not permissible, but dimensional wear along the back (involute) surface of the tooth, which, as can be seen from the graph, occurs much earlier. Note that the predicted dimensional wear of a tool with a protective coating should decrease by almost 1.5 times, which is a very positive factor that speaks for the applicability of coatings [9,10].



the boundary of the zone of technological (dimensional) wear for uncoated tools

the boundary of the zone of technological (dimensional) wear for coated tools

the wear curve (narrowing along the profile to the side) of the tool on the back surface without coating

the predicted wear curve (narrowing along the profile to the side) of the tool on the back surface with a coating

Fig. 3. The dependence of tool wear (on the back surface) h_b on the number of parts processed by it N.

4 Conclusion

Thus, as a result of the research, the article substantiates the use of modern wear-resistant coatings to improve the performance properties of a combined cutting and shaping tool designed for finishing cylindrical gears.

It should be noted that at the current stage of research conducted in this direction, the procedure for choosing the optimal type of coverage, based on the generalization of the expert assessment obtained by the a priori ranking method, becomes relevant.

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