Study of plates with a combined "steel base – (titanium, oxide) coating" structure and preliminary tests of its wear resistance

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Abstract. This paper presents the results of the study of plates with a combined "steel base – titanium, oxide coating" structure, which was obtained by resistive welding and strengthening induction heat treatment. The data of measurements of hardness and preliminary test for wear resistance were given. The possibility of finishing turning on structural chromium steel X40Cr13 was shown.

1. Introduction
When creating metal-cutting tools, the question of choosing a material that provides high performance and the required quality of surface treatment arises. Mechanical characteristics of the material, in particular hardness, are studied and the allowable machining conditions, such as the depth of cut, cutting speed and feed, are determined.

Known theoretical data cannot fully guarantee the operability of cutting tools, since they operate under the influence of a complex of factors, e.g. high contact stresses and temperatures, as well as intensive physical and chemical processes. Under these conditions, the structural elements of the cutting tools (edges and planes) wear out due to numerous effects, in particular abrasive (wear by hard particles of the processed material or the particles formed during processing), adhesive (sticking), fatigue (crack formation), oxidizing (the appearance of other phases and chemical compounds) and diffusion (gradual dissolution of the tool in the excess material).

It is known that cutting tools with nitride coatings have an increased service life compared to tools made of high speed steel (HSS) \cite{1,2}. A thin wear-resistant coating increases the surface hardness of the cutting tool, reduces the friction coefficient and has a heat-insulating effect on the cutting edge during processing.

Based on preliminary studies, the microhardness of the surface layer of titanium after induction heat treatment (IHT) reaches 3000–3500 HV \cite{3}. This value is comparable to the hardness of hard alloys and exceeds the hardness of high carbon and alloyed tool steels. However, titanium, even after strengthening treatment, does not have a sufficiently thick and wear-resistant layer. Thus, the modification of titanium is suitable for the initial titanium layers of small thickness, which are fixed on a hard base, e.g. from high-strength steel. One of the options for combining titanium with steel is welding, due to which titanium (about 1 mm thick) can be welded to chromium steel, e.g. X91CrMoV18 (analogue of 1.2361 steel) \cite{3}.

This paper presents the preliminary results of testing the wear resistance of a cutter with a replaceable metal-cutting plate of the combined "steel-base – (titanium, oxide) coating" structure.
2. Methodology
The combined "steel base – (titanium, oxide) coating" structure (STO) was formed by the consistent use of resistive welding (RW) of steel with a titanium plate with thickness $h$, grinding (to ensure a certain shape) and subsequent strengthening with high frequency currents.

When shaping, an important condition was the preliminary formation of cutting edges and radii of rounding (Figure 1).

![Figure 1. The design and geometrical parameters of the plate with a combined "steel base – (titanium, oxide) coating" structure](image)

The geometry of the tool used for the test was consistent with the type "SSLBR1212H09" (ISO 5608-80). The presented designations had the following meaning: S – pressing the plate to the holder in the hole with the help of a screw; S – the square shape of the cutting plate (all faces had the same length, all angles were 90°); L – type of the holder (angle 90°); B – the posterior angle of the plate (5°); R – processing direction, the right type of the holder; 12 – the cutter height, mm; 12 – the cutter width, mm; H – the cutter length equal to 100 mm; 09 – cutting edge length equal to 9.525 mm). This cutter geometry is used for basic turning operations, such as grooving and facing. The cutting properties were compared to a standard carbide cutting insert with a wear-resistant titanium-carbonitride coating (dark yellow color).

The hardness of the titanium part of the plate after strengthening IHT was evaluated using the Rockwell method a "TX PHR-2" tester according to the HRA scale. The microhardness of the oxide layer was specified using a "PMT-3" hardness tester with loads on the Vickers diamond indenter of 50–500 gf.

Preliminary tests of the wear resistance of the cutting elements of the combined plates under turning were performed on a "METALMASTER MML 180×300 V" lathe. The test material was a rod (machined length of 80 mm) made of stainless chrome steel X40Cr13 with a diameter of 15.6 mm. The hardness of the test material was 430–460 HV, which corresponded to 43–45 HRC (over 4 GPa). Processing was conducted with the following parameters: frequency – 500 rev/min, depth of cut – 0.4 mm, cutting speed – 23 m/min, feed rate – 1 mm/rev. In the course of cutting, wear of the main cutting edge was controlled (Figure 2).
Figure 2. A scheme, which shows finishing turning of X40Cr13 steel, where 1 – the raw surface of the rod, 2 – the machined surface, 3 – the combined plate, 4 – the cutter holder

The critical value corresponded to the linear wear of 0.3 mm or to a noticeable destruction of the tip and edges of the cutter (Figure 3).

Figure 3. Wear options of plates with oxide coatings: left side – plastic (1 – signs of wear); right side – fragile (2 – chipped vertex)
3. Results
The hardness of the steel-titanium assembly after the formation of a monolithic sample was characterized by elevated values compared to the initial materials (titanium, steel). This was due to the processes of accelerated heating, local melting and rapid cooling. This thermal cycle was similar to quenching with low- or medium-temperature tempering. The average hardness of steel reached 450–490 HV, whereas the microhardness of titanium increased from 150–180 HV to 300–320 HV. After strengthening IHT, the steel hardness reached 950–1200 HV (about 87–88 HRA) and the titanium layer had a hardness of at least 1350–1500 HV (at least 89–90 HRA).

The sample plate processed at a temperature of 1300–1350 °C and a holding time of at least 300 s had a maximum hardness over 92 HRA, while the microhardness prints were slightly visualized. Therefore, in further tests of wear resistance, the plates of this type were mainly studied. The plates with these coatings were tested during finishing, as the combined structure did not have sufficient rigidity, in particular the thickness of the modified layer.

When testing the wear resistance, the number of passes for the prototype was not less than 35–40, whereas for the experimental plate the wear resistance had a smaller value – 32–35. This was due to the small thickness of the strengthened layer compared to the thickness of the titanium layer \( h \). Therefore, further studies will be devoted to increasing the thickness of the hard layer and the rational choice of the thickness of the titanium layer.

The cutting plate of the combined structure was also tested during machining of medium carbon steel, brass and titanium. When processing these materials for the considered number of passes, the wear of the plate was not observed, which qualitatively characterized the high wear resistance of this material.

4. Conclusion
Thus, after strengthening IHT, the steel hardness reached 950–1200 HV (about 87–88 HRA), and the titanium layer was at least 1350–1500 HV (at least 89–90 HRA). The possibility of finishing machining of chromium steel X40Cr13 using a plate with a combined "steel base – (titanium, oxide) coating" structure was established. The proposed version of the plate was not practically inferior to the analog in terms of wear resistance (cutting capacity) at a frequency of 500 rev/min, depth of cut – 0.4 mm, cutting speed – 23 m/min and feed rate – 1 mm/rev.

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