Assessment results of the dependence of the processed surface quality on the applied tool material

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Abstract. Prior studies of surface roughness generated by machining the cutting edge of the tool does not remove the need for additional studies under specific processing conditions, for example, turning a specialized corrosion resistant stainless steel grade 09H17N7U. There are no regulatory recommendations to ensure the necessary quality of detail in the roughness parameters for this steel (pre-existing are outdated). The scope of application of this steel is rapidly expanding due to its unique performance properties, physical and mechanical characteristics. The authors performed such a study in relation to turning with various tool materials.

1. Introduction
In the manufacture of parts made of hard-to-handle materials, the manufacturer simultaneously has to solve several problems. For example, reducing the share of tool costs in the prime cost of a part manufacturing and ensuring the required quality of the part [1, 2, 3]. We considered a decrease in the share of tool costs by choosing the most rational metal-cutting tool and tool material. Of all the parameters characterizing the surface quality of the part, we examined the roughness of the treated surface. This indicator is significant from the perspective of many researchers. As a metal-cutting tool, standard interchangeable carbide inserts of domestic production are considered. As a substrate of instrumental material we used instrumental carbide grade VK8 (as a basic option). Several coating options applied to this substrate are considered.

Corrosion-resistant specialized stainless steel of the 09H17N7U grade, which is used for a number of critical parts of underwater vehicles and has been widely used in a number of industries due to its unique properties, was selected as a hard-to-handle material. The properties of this steel are partially reflected in table 1. These properties are mainly determined by the features of its chemical composition, for example, the large presence of chromium and nickel.

Table 1. Physico-mechanical characteristics of steel grade 09H17N7U.

| Tensile strength, MPa | Yield strength, MPa | Elongation at break, % | Impact strength KCU, kJ / m² | Heat treatment |
|----------------------|--------------------|------------------------|-----------------------------|---------------|
| 830                  | 735                | 12                     | 490                         | Hardening and high tempering |
Previous recommendations on the processing of this specialized steel are not applicable today due to the fact that they are outdated, if only because there is no longer the metal-cutting equipment that they were oriented to. Therefore, developing new recommendations is necessary. We have undertaken development of new recommendations only for longitudinal turning with standard interchangeable inserts when machining rigid (diameter about 200 mm, length 800 mm) workpieces on universal turning equipment (machine model 16K25) when the workpiece is installed in a three-jaw turning chuck and taper center of the tailstock of the machine. The use of a steady rest at half the length of the workpiece did not affect the results. The results were obtained with the following parameters of the cutting mode: cutting speed of 50 m/min, longitudinal feed rate of 0.21 mm/rev, cutting depth of 1 mm. The roughness of the treated workpiece surface was measured with a TR200 instrument using a TA-620 model rack. This device is widely used in experiments.

2. Results and discussion

1) The following tool materials were used:
   a) VK8 + TiCN (5 μm) + (TiAl)N (3 μm) + Al2O3 (5 μm) + TiC (5 μm) (the number in parentheses indicates the thickness of the coating layer);
   b) VK8 + Al2O3 (2 μm) + TiCN (5 μm) + (TiAl)N (3 μm) + TiN (3 μm);
   c) VK8 + (TiAl)N (3 μm) + Al2O3 (3 μm) + (TiAl)N (3 μm) + Al2O3 (3 μm);
   d) VK8 + TiN (3 μm) + TiC (3 μm) + TiN (3 μm) + TiC (3 μm);
   e) VK8 + TiC (3 μm) + TiN (3 μm) + (TiAl)N (2 μm);
   f) VK8 + TiCN (2 μm) + TiC (3 μm) + TiN (1,5 μm);
   g) VK8 + TiC (1,5 μm) + TiN (3 μm);
   h) VK8 + TiN (2 μm) + TiC (5 μm);
   i) VK8 + TiCN (0,5 μm) + TiN (1 μm);
   j) VK8 + TiN (0,5 μm) + TiC (1 μm);
   k) VK8 (basic option).

We selected these coatings of the VK8 substrate due to the fact that there were opportunities and equipment for their manufacture.

2) According to the capabilities of the TR200 instrument, the following six roughness parameters were used for roughness control: Rₘ – average arithmetic deviation of the profile, Rₐ – standard deviation of the profile, R₂ – height of the roughness of the profile by ten points, Rₜ – total height of the roughness, Rₚ – height of the largest protrusion of the profile, Rᵥ – the highest profile height.

3) The studies were performed on the example of turning with corrosion-resistant specialized stainless steel 09H17N7U at a cutting speed of 50 m/min, a longitudinal feed of 0.21 mm/rev, a cutting depth of 1 mm.

4) Interchangeable standard carbide inserts of square shape, rhombic shape, pentahedral shape, and trihedral shape were used.

5) The surface roughness was measured without removing the workpiece from the machine immediately on the surface obtained after 3 minutes turning. The surface area on which the roughness was measured was noted. Then the roughness was measured in the same areas with the workpiece removed from the machine. It was established that the roughness values coincided or differed in the third decimal place.

Similar measurements were performed on the surface formed by the cutting insert, which had some (about 0.3 mm) wear on the back surface. It was established that the trends in roughness values with a worn (0.3 mm) insert and an insert that worked for 3 minutes remained.

This research methodology largely coincides with the well-known [4–7] but differs in the specificity of the processed material and the applied instrumental materials.

A general idea of the test bench intended for these studies is given in figure 1.

The roughness parameters determined by the TR200 device for processing with different cutting inserts are shown in table 2. The model TR200 roughness control device with a model TA-620 stand
was used (TR200 operating mode – cyclic display of 2.5 mm values, \((n \times \text{cutoff})\) \(n\) cutting off step, 5, international standard ISO 4287) during turning (cutting conditions parameters cutting speed 50 m/min, workpiece speed 160 rpm, longitudinal feed rate 0.21 mm/rev, cutting depth 1 mm) specialized stainless steel 09H17N7U.

![Figure 1. Photo of the test bench: on the left is a workpiece; on the right is the TA-620 rack with the TR200 device.](image)

Table 2. The results of assessing the impact of tool material (and the shape of an interchangeable carbide insert) on the quality of the processed surface by its roughness.

| No of insert | Information about the material and parameters of the interchangeable insert | Roughness parameters and its values, \(\mu m\) |
|--------------|--------------------------------------------------------------------------------|-----------------------------------------------|
| 21           | MC2210                                                                          | \(R_a\) 5.030 \(R_q\) 5.806 \(R_z\) 21.31 \(R_t\) 28.87 \(R_p\) 11.14 \(R_v\) 10.17 |
| 19           | VK8 heat-sharpened and polished with a hole (circumference diameter 17.5 mm)    | \(R_a\) 8.605 \(R_q\) 9.433 \(R_z\) 29.90 \(R_t\) 31.42 \(R_p\) 16.20 \(R_v\) 13.69 |
| 18           | VP1255 (fine-grained base of the TT7K12 carbide (Co – up to 12%, WC = 81%; TiC = 4%; TaC = 3%) + three-layer coating (TiC-TiCN-TiN)) | \(R_a\) 6.204 \(R_q\) 7.070 \(R_z\) 24.06 \(R_t\) 28.05 \(R_p\) 12.03 \(R_v\) 12.02 |
| 20           | Square insert with a hole (diameter of the circumference 17.5 mm)               | \(R_a\) 9.283 \(R_q\) 10.67 \(R_z\) 36.30 \(R_t\) 39.74 \(R_p\) 16.73 \(R_v\) 19.56 |
5.5-1 5-faceted insert, coated with VK8

5.5-2 5-faceted insert coated with VK8 + (TiAl)N (3 μm) [deposition of coating layers by ion bombardment condensation]

Square insert without hole
(diameter of the circumference 16.5 mm, mark 1c)

The information in table 2 is difficult to analyze. To facilitate its comprehension, the authors suggest using a technique for comparing parameters, namely, a comparison by the relative value of the comparison as the ratio of the differences between the maximum and minimum values to the maximum value:

\[ B_1 = \frac{\text{the maximum and minimum values}}{\text{the maximum value}}. \]

Let us explain this by comparing the values of \( R_a \) for the surface roughness obtained by processing with an insert No. 19 (see table 2) or an insert No 5.5-1. For the insert No19, \( R_a = 8.605 \) μm. For the insert No 5.5-1, \( R_a = 7.1 \) μm. Then

\[ B_1 = \frac{(8.605 - 7.1)}{8.605} = 17.5. \]

The number 17.5 to some extent shows how the values of \( R_a \) are relatively different from each other. For convenience, this figure can be converted into conditional percentages by multiplying \( B_1 \) by a conditional 100%, i.e.:

\[ B_2 = B_1 \times 100\% = 1750\%. \]

The same calculation for \( R_b \) show the following:

\[ B_1 = \frac{(16.28 - 16.2)}{16.28} = 0.5. \]

Accordingly, one can conclude that for these inserts the difference in the parameter \( R_b \) is much smaller than in the parameter \( R_a \).

Examples of similar calculations for other parameters are given in table 3.

**Table 3.** Examples of a comparative assessment of the difference in parameters, μm, surface roughness of the part after processing with different inserts.

| Insert No 23, VK8 heat-sharpened and polished with a hole (circumference diameter 17.5 mm) | Insert No 5.5-1 5-faceted, coated with VK8 | The relative value of \( B_1 \) differences in roughness parameters | The value of \( B_2 \) differences in roughness parameters, % |
|---|---|---|---|
| \( R_a \) | 17.5 μm | 8.605 | 7.10 |
| \( R_a \), μm | | 9.433 | 8.25 |
| \( R_b \), μm | 29.9 | 28.95 |
| \( R_c \), μm | 31.42 | 30.97 |
| \( R_d \), μm | 16.2 | 16.28 |
| \( R_e \), μm | 13.69 | 12.66 |
The results obtained allow for the following conclusions:

1) The surface roughness parameters depend on many factors associated with the properties of the material of the cutting inserts and its geometry.

2) The values of the roughness parameters are not equivalent when using inserts of different shapes and geometry, the presence of coating on the plate also matters. This is most noticeable when comparing the roughness parameters of inserts having different shapes and with different instrumental materials.

3) Of above-mentioned inserts, the best roughness parameters of the processed surface of the workpiece are achieved using the insert MC2210. Moreover, this same insert not only provides better roughness, but also a quite acceptable period of working capacity (180 minutes before reaching a wear of 0.5 mm). For comparison, a 4-faceted insert, material VK8, heat-sharpened and polished with a hole (the circumference diameter is 17.5 mm) has a working period of 160 minutes.

3. Conclusion
This research proves by the example of turning steel of 09H17N7U grade steel that there is an interrelation between the quality (six roughness parameters) of the processed surface and the operational properties of the tool material. From the considered nomenclature of materials and geometry of interchangeable cutting inserts, the most efficient were identified. It allows using the results as recommendations and recommending the proposed methodology for choosing an efficient instrumental material.

The scientific novelty of research is establishing the interrelation between the quality of the processed surface (in terms of roughness parameters) and the tool material used (as well as the shape of the interchangeable cutting insert and the topography of its front surface) during turning of specialized stainless steel 09H17N7U. The practical significance of the research consists in the selection of the most informative roughness parameters, in the development of a methodology for selecting tool material for the required quality of the processed surface.

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