THE INFLUENCE OF THE GEOMETRY OF THE CUTTING EDGE AND MACHINING PARAMETERS OF DUPLEX CAST STEEL AFTER TURNING

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Abstract

The development and research activity is connected to the production of newer and more functional products. Innovative processes are being developed and applied; services and projects are delivered. Products are work items that should be initially designed, manufactured and finally sold and utilized. Examples of products may be airplanes, ships, cars, machine tools, gears, crankshafts, drive shaft, tubes as well as gasoline, electricity and gas, etc. The product has to meet the expectations of the future use. It is characterized by a set of functional features. In the case of machines and their capabilities and performance, for example, durability, reliability, resulting from the characteristics represented by the structural units forming the structure. The formation of the desired features of the surface layer in the technological process is an important problem due to the ability of the elements of kinematic pairs to fulfill the function as long as possible foreseen for them. The article presents results of experimental studies of turning cast steel grade GX2CrNiMoCuN25-6-3-3. The aim of the research was to determine the geometry of the cutting edge and the technological parameters of cutting that are conducive to obtaining the roughness in the field of very accurate machining. It can achieve the appropriate technological quality of the workpiece surface. After these experimental studies was determined that there is a reduction roughness using suitable inserts. Turning was made for the duplex cast steel. The technological parameters of machining process were used: feed rate \( f = 0.1-0.2 \text{ mm/rev} \), depth of cut \( d_p = 0.5 \text{ mm} \), cutting speed \( v_c = 50-100 \text{ m/min} \). Turning was made using universal lathe CDS 500x1000 equipped with CCMT carbide tipped inserts.

Keywords: turning, finishing, forming surface layer, surface roughness reduction, duplex cast steel

1. Introduction

The properties of the surface layer together with the accuracy of manufacture are necessary to obtain the appropriate technological quality of the product. The technological quality of the product is understood as a set of features obtained after the end of the manufacturing process, which should be treated equally as they are interrelated. At the stage of operation of the product's quality is revealed as a quality performance. The quality of the product in use is determined by the functionality, durability, wear resistance, reliability, economic indicators acquisition and use, and aesthetics and other features. The usable quality of the surface layer is often one of the factors determining the usable value of the product (element, part, assembly), i.e. its suitability to perform the operational functions of the machine or device. Thus, there is a need to shape the desired properties of the surface layer by selecting appropriate technological processes [1-14].

The quality of the surface layer of cooperating machine parts, obtained in the technological process, determines their operational properties. It is estimated that about 80-85% of damage to parts of machines is located in the surface layer, which occupies only a few percent of the volume of the whole element. On the basis of tests, it was found that fatigue strength could be improved by 50-70% by reducing roughness, by 20-30% by strengthening the surface layer and by 10-20% by
introducing compressive stresses [1, 3, 14, 17]. Fig. 1 was presented a laboratory stand for longitudinal turning of external cylindrical surfaces.

Fig. 1. The laboratory stand for longitudinal turning of external cylindrical surfaces

One of the finishing treatments used to shape the surface layer of the product is machining. Turning is a treatment that involves shaping the surface properties of a surface using a cutting tool with the right blade geometry. The essential feature of turning is the proper matching of the rotational movement of the workpiece and the linear motion of the tool. As a result, the surface is formed of appropriate shape and dimensions in cutting conditions legitimate technically and economically.

2. Research methodology

Experimental research was carried out in the Laboratory of Production Engineering of Department of Marine Maintenance of the Faculty of Marine Engineering of the Gdynia Maritime University. External cylindrical surfaces were prepared for finishing machining by medium longitudinal turning on a CDS 500x1000 universal turning lathe. Cutting parameters were selected based on own research.

The criterion for selecting the right cutting-tool inserts geometries for very precise machining was the arithmetic mean of the ordinates of the surface roughness profile, which should be within the range $Ra = 0.16-1.63 \, \mu m$. Therefore, different types of inserts were proposed for finishing machining (refer with Tab. 1): CCMT 09T304-UM, CCMT 09T308-UM, CCMT 09T308-MM, where all are made of sintered carbides of the 2025 grade with a CVD Ti(C,N)/Al$_2$O$_3$/TiN (2 $\mu m$/1.5 $\mu m$/2 $\mu m$) [20].

Tab. 1. The shape and grade inserts used for longitudinal turning of cylindrical samples with cast steel duplex GX2CrNiMoCuN25-6-3-3

<table>
<thead>
<tr>
<th>Insert Shape</th>
<th>Insert Type</th>
<th>Insert Grade</th>
<th>Nose Radius [mm]</th>
<th>Flank Angle [°]</th>
<th>Rake Angle [°]</th>
</tr>
</thead>
<tbody>
<tr>
<td>CC09T3</td>
<td>CCMT 09T308-MM</td>
<td>2025</td>
<td>0.8</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>CC09T3</td>
<td>CCMT 09T308-UM</td>
<td>2025</td>
<td>0.8</td>
<td>7</td>
<td>6</td>
</tr>
<tr>
<td>CC09T3</td>
<td>CCMT 09T304-UM</td>
<td>2025</td>
<td>0.4</td>
<td>7</td>
<td>6</td>
</tr>
</tbody>
</table>
The Influence of the Geometry of the Cutting Edge and Machining Parameters of Duplex Cast Steel After Turning

The tools are characterized by the following features: tool cutting edge angle $\kappa_r = 90^\circ$, tool included angle $\varepsilon_r = 80^\circ$, rake angle $\gamma = 6-7^\circ$, flank angle $\alpha = 7^\circ$, nose radius $r_e = 0.4-0.8$ mm.

For the tests, the cutting parameters were used: feed rate $f = 0.1-0.2$ mm/rev, depth of cut $a_p = 0.5$ mm, rotational speed $n = 600-1220$ rpm, cutting speed $v_c = 50-100$ m/min.

Throughout of the longitudinal turning of cylindrical samples with cast steel duplex GX2CrNiMoCuN25-6-3-3 is usually short durability of the inserts. It is therefore important to determine the length of spiral cutting. This is the length cutting, which are chosen for recommended cutting, thus allowing for a reliable process. Length of spiral cutting is a constant ($L_{sc} = 10.5$ m) and applied to the insert, geometry, and grade, depth of cut and material that shall be subject machined. Length of spiral cutting ($L_{sc}$) can be calculated from the formula:

$$L_{sc} = \frac{\pi D_m l_m}{f},$$

where:

$D_m$ – the diameter of the workpiece in the machined surface, [mm], $\phi 27$ mm,

$l_m$ – length of the cutting surface, [mm],

$f$ – feed rate, [mm/rev].

After the turning process were measured using a profilometer Hommel Tester T1000. The surface roughness measurements were performed to the principles contained in standards with the measurement lengths of 4.8 mm and 0.8 mm for the elementary section. A number of parameters of surface roughness after cutting were determined, among other things; parameters were defined associated with the material ratio curve.

The experimental researches were made for samples from the GX2CrNiMoCuN25-6-3-3 duplex cast steel, with the chemical composition is given in Tab. 2. The ferritic - austenitic cast steel called duplex is subjected of many material and technological analyses, it is characterized with higher tensile strength and better resistance to stress corrosion in comparison to austenitic steels [7, 8-10, 15, 16, 19].

### Tab. 2. The chemical composition of duplex cast steel GX2CrNiMoCuN25-6-3-3 [%mass] [19]

<table>
<thead>
<tr>
<th>C [%]</th>
<th>Cr [%]</th>
<th>Ni [%]</th>
<th>Mo [%]</th>
<th>Cu [%]</th>
<th>Mn [%]</th>
<th>N [%]</th>
<th>Si [%]</th>
<th>S [%]</th>
<th>P [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.024</td>
<td>25.62</td>
<td>6.52</td>
<td>2.98</td>
<td>2.55</td>
<td>0.97</td>
<td>0.25</td>
<td>0.86</td>
<td>0.010</td>
<td>0.008</td>
</tr>
</tbody>
</table>

Measures forces were used for tool dynamometer DKM2010. Force on the cutting tools is measured up to 2000 N and as option temperatures on the tool tip between 300°C to 800°C.

### 3. Results of experimental research

An experimental test of finishing turning of external cylindrical surfaces was performed in the Laboratory of Production Engineering located in the Department of Marine Maintenance at the Faculty of Marine Engineering of the Gdynia Maritime University. After the experimental study it was determined that, the roughness is significantly affected by the technological parameters of the longitudinal turning of cylindrical samples.

Table 3 shows exemplary results of measurements of surface roughness after finishing turning of the samples with the duplex steel, for different values of cutting speed and feed rate, and the constant cutting depth. $R_a$ is the arithmetic mean roughness value from the amounts of all profile values. $R_z$ is maximum height of profile average value of the five measurement. These parameters are according to norm ISO 4287. The surface roughness reduction ratio ($K_{Ra}$) [3] is determined by the arithmetical mean deviation quotient before to after turning.
Tab. 3. The example of measurements of the parameter of surface roughness for inserts used for turning cylindrical samples with cast steel duplex GX2CrNiMoCuN25-6-3-3

<table>
<thead>
<tr>
<th>No of Samples</th>
<th>Insert Type and Grade</th>
<th>$v_c$ [m/min]</th>
<th>$f$ [mm/rev]</th>
<th>$a_p$ [mm]</th>
<th>$R_z$ [$\mu$m]</th>
<th>$R_a$ [$\mu$m]</th>
<th>$K_{Ra}$ [-]</th>
</tr>
</thead>
<tbody>
<tr>
<td>09T308-MM-100</td>
<td>CCMT 09T308-MM 2025</td>
<td>100</td>
<td>0.2</td>
<td>0.5</td>
<td>9.19</td>
<td>1.93</td>
<td>1.71</td>
</tr>
<tr>
<td>09T308-MM-70</td>
<td>CCMT 09T308-MM 2025</td>
<td>70</td>
<td>0.2</td>
<td>0.5</td>
<td>8.41</td>
<td>1.54</td>
<td>2.14</td>
</tr>
<tr>
<td>09T308-MM-50</td>
<td>CCMT 09T308-MM 2025</td>
<td>50</td>
<td>0.2</td>
<td>0.5</td>
<td>11.97</td>
<td>2.31</td>
<td>1.43</td>
</tr>
<tr>
<td>09T308-UM-100</td>
<td>CCMT 09T308-UM 2025</td>
<td>100</td>
<td>0.2</td>
<td>0.5</td>
<td>7.55</td>
<td>1.53</td>
<td>2.16</td>
</tr>
<tr>
<td>09T308-UM-70</td>
<td>CCMT 09T308-UM 2025</td>
<td>70</td>
<td>0.2</td>
<td>0.5</td>
<td>7.44</td>
<td>1.55</td>
<td>2.13</td>
</tr>
<tr>
<td>09T308-UM-50</td>
<td>CCMT 09T308-UM 2025</td>
<td>50</td>
<td>0.2</td>
<td>0.5</td>
<td>7.95</td>
<td>1.63</td>
<td>2.02</td>
</tr>
<tr>
<td>09T304-UM-70-2</td>
<td>CCMT 09T304-UM 2025</td>
<td>70</td>
<td>0.2</td>
<td>0.5</td>
<td>13.85</td>
<td>3.03</td>
<td>1.09</td>
</tr>
<tr>
<td>09T304-UM-70-1</td>
<td>CCMT 09T304-UM 2025</td>
<td>70</td>
<td>0.1</td>
<td>0.5</td>
<td>5.28</td>
<td>1.03</td>
<td>3.21</td>
</tr>
</tbody>
</table>

The arithmetical mean deviation of the roughness profile of the surface after turning for the cutting parameters: $v_c = 70$ m/min, $f = 0.2$ mm/rev, $a_p = 0.5$ mm is $R_a = 1.55$ µm, while the maximum height of profile is equal to $R_z = 7.44$ µm (refer with Tab. 3). Comparing the roughness by using different geometries and types of cutting inserts for fixed values of the cutting parameters: $v_c = 70$ m/min, $f = 0.2$ mm/rev, $a_p = 0.5$ mm, it can be seen (Fig. 2) that the machined surface of steel samples after turning with the cutting insert CCMT 09T308-UM 2025 obtains low values of roughness parameters. The surface roughness reduction ratio was one of the largest $K_{Ra} = 2.13$. Taking into account the use of different feed values for the remaining constant cutting parameters, it can be seen (refer with: Tab. 3) that for a smaller feed rate of $f = 0.1$ mm/rev, with a constant cutting speed $v_c = 70$ m/min and depth of cut $a_p = 0.5$ mm, using a CCMT 09T304-UM 2025 cutting insert, even lower values of roughness parameters are obtained than for the other machined surfaces using feed rate $f = 0.2$ mm/rev. The surface roughness reduction ratio was equal to $K_{Ra} = 3.21$, which is the highest value among the presented scope of research (Fig. 3).
After the analysed data and dependencies presented in Tab. 3 and Fig. 2 and 3 it can be defined that to achieve a reduction in surface roughness after the longitudinal turning finishing of the samples of the duplex steel, should be use specified parameters $v_c = 70$ m/min, $f = 0.2$ mm/rev, $a_p = 0.5$ mm for the cutting insert CCMT 09T308-UM 2025 or $v_c = 70$ m/min, $f = 0.1$ mm/rev, $a_p = 0.5$ mm for cutting insert CCMT 09T304-UM 2025.

On the Fig. 4 is shown an example of cutting forces for turning of the cutting insert CCMT 09T308-UM 2025 with duplex cast steel, for feed rate $f = 0.2$ mm/rev and cutting speed $v_c = 70$ m/min and depth of cut $a_p = 0.5$ mm. This type of distribution of cutting forces is characteristic of the research program. The main cutting force assumes the highest values of $F_c = 390$ N, while the feed force has the smallest value of $F_f = 100$ N, and the resisting force assumes the values $F_p = 250$ N (Fig. 4). The cutting force measurement was carried out in each cutting pass using dynamometer DKM2010.
After the experimental testing carried out, with the given technological parameters of the machining of external cylindrical surfaces, it was determined that the geometry and grade of the cutting insert as well as the technological parameters of the machining have an impact on the reduction of roughness and the correct distribution of cutting forces.

4. Summary

In the article were presented the influence of the geometry of the cutting edge and machining parameters of duplex cast steel after longitudinal turning on the surface roughness reduction ratio.

The forming surface layer of duplex cast steel in the GX2CrNiMoCuN25-6-3-3 grade was carried out by longitudinal finishing of external cylindrical surfaces. Precise machining was carried out at given different cutting parameters: feed rate $f = 0.1 \text{-} 0.2 \text{ mm/rev}$, depth of cut $a_p = 0.5 \text{ mm}$, cutting speed $v_c = 50 \text{-} 100 \text{ m/min}$. Turning was made using universal lathe CDS 500x1000 equipped with CCMT 09T304-UM, CCMT 09T308-UM, CCMT 09T308-MM carbide tipped inserts of the grade 2025 with applied coating by CVD method.

Turning the duplex steel to obtain a smooth surface should be carried out using the cutting insert CCMT 09T304-UM 2025 for the nose radius $r_\varepsilon = 0.4 \text{ mm}$ with cutting parameters: feed rate $f = 0.1 \text{ mm/rev}$, cutting speed $v_c = 70 \text{ m/min}$, depth of cut $a_p = 0.5 \text{ mm}$. It would also be possible to use CCMT 09T308-UM 2025 and CCMT 09T308-MM 2025 cutting inserts with a higher value of the nose radius $r_\varepsilon = 0.8 \text{ mm}$ for precision machining, then should be used feed rate $f = 0.2 \text{ mm/rev}$ and cutting speed $v_c = 70 \text{ m/min}$ and depth of cut $a_p = 0.5 \text{ mm}$.

The production of manufactured products used in components of machines it is essential them to be assured required technological quality of the surface layer. The one of machining used to form technological and mechanical properties of the surface layer is longitudinal turning.

The objective of the experimental testing was to determine the geometry of the cutting edge and the cutting parameters that are propitious to receive the roughness in the field of very accurate machining. It may achieve the appropriate technological quality surface of the workpiece. After the experimental investigations of machining, it was determined that there was a reduction in the surface roughness using the appropriate cutting edge geometry and for the given technological cutting parameters: $v_c = 70 \text{ m/min}$, $f = 0.2 \text{ mm/rev}$, $a_p = 0.5 \text{ mm}$ for the cutting insert CCMT 09T308-UM 2025 or $v_c = 70 \text{ m/min}$, $f = 0.1 \text{ mm/rev}$, $a_p = 0.5 \text{ mm}$ for cutting insert CCMT 09T304-UM 2025.

References


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Manuscript received 10 July 2018; approved for printing 12 September 2018.