INTRODUCTION

Stainless steels currently enjoy high interest shows that every year takes place a few percent increase in production. Differentiation of properties, depending on the chemical composition, microstructure, quality of the surface layer, constantly expand the application areas of these materials. A special group are ferritic-austenitic steels (duplex steels hereinafter) whose development allows to increase the durability of machine parts exposed to erosion and corrosion wear. The combination of high mechanical strength, high corrosion resistance and relatively low cost compared to similar materials, contributed to making duplex stainless steels one of the fastest growing groups of stainless steels. The duplex stainless steels are two-phase chromium-nickel-molybdenum-iron alloys in which the proportions of the components allow optimization of the equilibrium of the volume fractions of austenite and ferrite [1-13]. Two-phase stainless steel is considered to be difficult-to-cut materials. It is therefore important to determine the cutting edge wear [4-6, 10, 14]. The wear of the turning tool occurs on all surfaces with direct contact with the workpiece material and is manifested by the loss of the tool material. The most frequently determined are indicators of wear of a turning knife-edge, such as: flank wear (VB) and distance between primary cutting edge and the most distant - crater wear (KB).

EXPERIMENTAL MATERIALS AND METHODS

Two-phase stainless steels known as duplex by treatment have physical properties similar to those of the ferritic steels, while, due to the chemical composition and resistance to corrosion are similar to austenitic steel. The experimental research was carried out in the Laboratory of Department of Marine Maintenance of the Faculty of Marine Engineering of the Gdynia Maritime University. The external cylindrical surfaces were prepared for machining process by universal turning lathe.

Cutting parameters were selected based on own research for longitudinal turning: feed rate \( f = 0.1 \times 0.2 \text{ mm/rev} \), depth of cut \( a_c = 0.5 \text{ mm} \), cutting speed \( v = 50 \times 100 \text{ m/min} \), on the maximum tool flank wear VB. Surface machining was carried out with inserts CCMT where all are made of sintered carbides of the 2025 grade. The criterion for selecting the right cutting-tool insert geometries for very precise machining was the arithmetic mean of the ordinates of the surface roughness profile (Ra= 0.16 \times 1.25 \text{ mm}) and maximum tool flank wear (VB = 200 \text{ mm}).

Throughout the longitudinal turning of samples with duplex stainless steel (DIN EN 1.4410, PN-EN X2CrNiMoCuN 25-7-4, AISI 2507) (Table 1.) is usually short durability of the cutting inserts.

| C [%] | Cr [%] | Ni [%] | Mo [%] | Mn [%] | Si [%] | N [%] | S [%] | P [%] |
|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| 0.05  | 25.0  | 7.0   | 4.0   | 2.0   | 1.0   | 0.35  | 0.015 | 0.035 |

| Rho2 [MPa] | Rho [MPa] | Rho [MPa] | \( \alpha_t \) [%] | HV [GPa] | E [GPa] | \( \rho \) [kg/dm\(^3\)] | \( \lambda \) [J/m \cdot s \cdot K] | \( c_v \) [kJ/kg K] |
|-----------|-----------|-----------|-----------------|----------|--------|----------------|----------------|------------|
| 550       | 750       | 1500      | 15              | 310      | 200    | 7.8            | 15            | 500        |

Observation and measurement of the tool wear after turning of duplex stainless steel samples was carried out using Scanning Electron Microscopy EVO MA 15 (Fig. 1). The Scanning Electron Microscope Zeiss EVO MA 15 is a device designed for examining the microstructure of solids. The device allows the imaging electron samples with a resolution of 3 nm at 30 kV. The range of possible magnification range from 5 to 1 000 000 times. The microscope enables the observation of samples with a mass up to 500 grams (at full mobility of the microscope table in XYZ directions) or up to 5 kilograms (then the table motion is limited to the XY axis directions). The microscope enables observation of samples as well as measurements of geometric quantities. The microscope is additionally equipped with an EDS analyzer. Energy Dispersive Spectrometer (EDS) XFlash 6/30 by Bruker extends the research possibilities of scanning electron microscopy with accurate and fast chemical analysis (qualitative and quantitative) of the observed surface of metallographic specimens.
RESULTS OF RESEARCH

After turning finishing duplex stainless steel, it was determined that the machining parameters affect the surface quality and knife wear. A number of roughness parameters have been defined. The smallest values of the parameter arithmetical mean deviation of the roughness profile $Ra = 1.55 \, \mu m$ were determined after turning with the cutting insert CCMT 09T308-UM 2025 for the cutting parameters: $v_c = 70 \, m/min$, $f = 0.2 \, mm/rev$, $a_p = 0.5 \, mm$.

Even smaller values of the $Ra = 1.05 \, \mu m$ parameter were determined for the cutting parameters: 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 cutting insert carbides of the 2025 grade with a CVD Ti(C,N)/Al$_2$O$_3$/TiN (2μm/1.5μm/2μm) [14].

The cutting inserts were characterized by the following features: cutting edge angle $\kappa_e = 90^\circ$, tool included angle $\gamma_t = 80^\circ$, rake angle $\gamma = 6^\circ$ and $\gamma_g = 7^\circ$, flank angle $\alpha = 7^\circ$, nose radius $r_e = 0.4 \, mm$ and $r_g = 0.8 \, mm$. For this turning tool, the smallest flank wear $VB = 36 \, \mu m$ and crater wear $KB = 18 \, \mu m$ was obtained (Fig.2). The surface roughness reduction ratio was equal to $K_{Ra} = 3.21$, which is the highest value among the presented scope of research.

The wear of cutting edge shown a view from the scanning electron microscope of the cutting inserts. The condition of used tool point surfaces was assessed using the corresponding SEM images shown in Figures 2 to 4. You can see the effects of wear on the rake face and flank. For cutting inserts with nose radius 0.8 mm the built-up edge with the clash of the major flank can be observed. However, on the cutting insert with a radius of 0.4 mm there is slight wear in the form of abrasive wear.

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**Fig. 1** Scanning Electron Microscopy EVO MA 15

**Fig. 2** The microscopic view of flank (a) and rake face (b) wear for CCMT 09T304-UM 2025 cutting insert
The wear was measured using software dedicated to microscopy and the results are shown in Table 2. The arithmetical mean deviation of the roughness profile of the surface and maximum height of profile average value of the five measurement was shown in Table 2 and Figures 5.

### Table 2 The measurements of the parameter of surface roughness for inserts used for turning cylindrical samples and example indicators of wear of a cutting edge

| No samples | Insert Shape | \( f \)  [mm/rev] | \( v_c \)  [m/min] | \( R_z \)  [\( \mu \)m] | \( R_a \)  [\( \mu \)m] | \( K_a \)  [\( \mu \)m] | \( V_B \)  [\( \mu \)m] | \( K_B \)  [\( \mu \)m] |
|------------|--------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|
| 08-MM-100  | CCMT 09T308-MM | 0.2               | 100               | 9.19              | 1.93              | 1.71              | 241.7             | 120.9             |
| 08-MM-70   | CCMT 09T308-MM | 0.2               | 70                | 8.41              | 1.64              | 2.14              | 194.1             | 97.1              |
| 08-MM-50   | CCMT 09T308-MM | 0.2               | 50                | 11.97             | 2.31              | 1.43              | 292.2             | 146.1             |
| 08-MM-100  | CCMT 09T308-MM | 0.2               | 100               | 7.55              | 1.53              | 2.16              | 111.4             | 55.7              |
| 08-MM-70   | CCMT 09T308-MM | 0.2               | 70                | 7.44              | 1.55              | 2.13              | 96.4              | 48.2              |
| 08-MM-50   | CCMT 09T308-MM | 0.2               | 50                | 7.95              | 1.63              | 2.02              | 141.2             | 70.6              |
| 04-MM-70-2 | CCMT 09T304-UM | 0.2               | 70                | 13.85             | 3.03              | 1.09              | 64.7              | 32.3              |
| 04-MM-70-1 | CCMT 09T304-UM | 0.1               | 70                | 5.33              | 1.05              | 3.21              | 35.9              | 17.9              |

**Fig. 3** The microscopic view of flank (a) and rake face (b) wear for CCMT 09T308-MM 2025 cutting insert

**Fig. 4** The microscopic view of flank (a) and rake face (b) wear for CCMT 09T304-UM 2025 cutting insert

**Fig. 5** The arithmetical mean deviation (Ra) and the maximum height of profile (Rz)

The criterion of the smallest roughness and the highest wear was proposed. The criterion for selecting the right cutting inserts geometries for finishing was the arithmetical mean deviation of the ordinates of the surface roughness profile, which should be within the range from 0.16 \( \mu \)m to 1.25 \( \mu \)m and the second criterion is of the maximum tool flank wear 200 \( \mu \)m. It can therefore be concluded that the tools used for testing meet the wear criterion. The cutting tools meet the criterion with the exception of insert shape CCMT 09T308-MM (Fig. 6).

After the analysis experimental research can be defined that to achieve a reduction in surface roughness after the longitudinal turning finishing of the samples of the duplex stainless steel, should be use with a constant cutting speed \( v_c = 70 \) m/min and depth of cut \( a_p = 0.5 \) mm for feed rate \( f = 0.1 \) mm/rev for cutting insert CCMT 09T304-UM 2025 where is the smallest flank wear \( V_B = 36 \) \( \mu \)m.
The turning of external cylindrical surfaces of duplex stainless steel was carried out by inserts shape CC09T3 of the grade 2025 with applied coating by CVD method.

Turning the duplex steel to obtain a smooth surface should be carried out using an arithmetic mean deviation of the roughness profile of the surface after turning is equal $Ra = 1.05 \, \mu m$. Therefore, for the finishing of duplex steel, it can be proposed insert type CCMT 09T304-UM2025 meet the quality criterion, where $Ra$ parameter is less than the value of 1.25 $\mu m$ and the wear criterion of the maximum tool flank wear $VB = 200 \, \mu m$.

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**CONCLUSION**

In the paper were presented the influence of the geometry of the cutting edge and machining parameters of duplex stainless steel after finishing turning on the surface roughness reduction ratio and flank wear.

The turning of external cylindrical surfaces of duplex stainless steel in was carried out by inserts shape CC09T3 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 for the nose radius $r_n = 0.4 \, \text{mm}$ with cutting parameters: feed rate $f = 0.1 \, \text{mm/rev}$, cutting speed $v_c = 70 \, \text{m/min}$, depth of cut $a_p = 0.5 \, \text{mm}$.

There arithmetical mean deviation of the roughness profile of the surface after turning is equal $Ra = 1.05 \, \mu m$. Therefore, for the finishing of duplex steel, it can be proposed insert type CCMT 09T304-UM 2025, where is the smallest flank wear $VB = 36 \, \mu m$ and crater wear $KB = 18 \, \mu m$ and surface roughness reduction ratio $K_{10u} = 3.21$ was equal.