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Surface Roughness, Topography, Accuracy, Chip Formation Analysis & Investigation of M390 and M398 Steels after Hard Machining

Jozef Majerík (0000-0002-6577-1987), Juraj Majerský (0000-0003-2342-0852), Igor Barényi (0000-0002-9296-600X), Henrieta Chochlíková (0000-0003-4938-129X), Jana Escherová (0000-0002-4203-2495), Mária Kubasáková (0000-0003-2908-3439)
Faculty of special technology, Alexander Dubcek University of Trencin. Ku kyselke 469, 911 06 Trencin. Slovakia. E-mail: jozef.majerik@tnuni.sk

Article deals with processing of intermetallic materials produced by powder metallurgy M390 and M398 Microclean® produced by Böhler. Main interest is the analysis & measurement of their surface roughness and topography after the processing by DNMG and WNMG geometry of cutting inserts with 0.4 and 0.8 mm radius after hard turning at the same process parameters for both materials and all types of cutting inserts. The comparative studies were carried out for the microgeometrical and chip formation research on the machined surfaces and the technological processes were assessed, including chip diagrams. Spectral analysis was used to verify the composition of investigated materials by spectral analysis measuring device. In order to examine the surfaces in detail, in addition to the standard roughness measurement, surface topography was performed by the coherent correlation interferometric microscope. The results of surface roughness as well as topography show higher wear resistance of M398 material compared to M390. This was confirmed indirectly by the fact that it is primarily shown by the higher surface roughness of M398 after machining under the same conditions. These properties are obtained by a higher content of additive elements, respectively of their carbides. Based on the conclusions of these experiments, additional knowledge and recommendations for the processing of these materials were created.

Keywords: Surface Roughness, Surface Topography, Cutting Parameters, Chip Formation, PM Steels

1 Introduction

Metal materials used for processing of plastics used on injection moulding machine, or in the injection moulding tools are commonly charged by mechanical stress, high temperatures, high pressure, abrasion, or chemical influences. Due to that reason producers of the metal materials in cooperation with plastic industry devices producers developed materials which resist all this conditions.

Processing of powder metallurgy materials, especially those produced by Hot Isostatic Pressing (HIP) method is very difficult. These intermetallic materials have very high toughness and resistance against wear in base state, already. It is mainly due to high quality, minimal defects of lattice and high content of additional components [1 - 3]. Materials produced by powder metallurgy are very interesting especially from the composition scope of view. By this technology there is possible to produce alloys which are not producible by conventional metallurgical processes. This is clearly visible on the investigated materials from company Böhler, producer of materials M390 Microclean® and M398 Microclean®. The base matrix of PM steels M390 and M398 Microclean® is created by Ferrite in which the additional components and its carbides are placed. Placement of additional components increases anti abrasive properties of material, as was mentioned in article of A. Blutmager et al. [6], abrasive influences affect mainly the base material matrix, while additional components, mostly as carbide forms maintain their position as long as possible, therefore they act like a resistance against cutting tool also in base – Ferritic state of matrix.

The PM (Powder Metallurgy) steels produced by the HIP method are characterized by high toughness, similar to SPS (Spark Plasma Sintering). These methods eliminate the main problem of powder materials due to their huge porosity [7 - 8]. During the processing of porous material, the cutting tool works practically in the regime of intermittent cutting due to micro cavities between individual grains [9], which causes inhibition of heat distribution in the material [10] and by that negative influence for the cutting tool. Such porous materials are produced by sintering methods in which adequate pressure for the junction of material powder grains is not generated and they are sintered as placed in relative distances, which causes remaining of some space between them. Of course, grains are partially melted and joined, but the pressure is not high enough to eliminate the distances between material powder grains.

There are more methods how to increase properties of this type of product and it was tested by several scientific teams. Klink, Guo and Klocke [12] studied Wire-EDM (Electro Discharge Machining) and checked the surface integrity after the process. They found out that while using water-based dielectrics in this process there is a higher tensile residual stress in comparison with the using of the chemical Wire-EDM process, but altogether the W-EDM process affects in very negative way to surface integrity.

Mehmeti et al. [13] tried to get best surface integrity on the products produced by MIM (Metal Injection Moulding) and L-BPF (Laser-Based Powder Bed Fusion) processes and followed by HIP. They were successful and produced structures nearly without pores or another defect. Thanks to that they increased the resistance against brittle fracture. Improvement was interpreted mainly by growing of the grain and migration of pores to grain borders of MIM part.

Ociepa, Jenek and Yagolnitser [14] analysed the effect of the cutting inserts based on cubical boron nitride with selected cutting parameters of turning technology for the chip formation during finishing process of hardened tool steels. One of selected steels was Vanadis 4 EXTRA SuperClean® (V4). During the process authors found out that for this PM steel a wide range of parameters exists where the chip is formed in useful shape. By the low value of feed rate, approx. under 0.1 $mm.rev^{-1}$. there is tendency to create long spiral chips or long straight chip segments, which can harm the surface of workpiece. The most advantageous shape of chip for PM steel was found from feed rate 0.1 to 0,15 $mm.rev^{-1}$, independently from the shape of changeable cutting insert. [14]

The influence of the cutting tool edge geometry on the resulting roughness of the machined surface after turning tool steels was investigated by Ventura et al. [15] as well as the team of authors Zhao T. et al. [16]. Their research was focused on AISI 52100 and 4140 steels. In their research they focused on aspects of 2D and 3D surface roughness, topography and the influence of the cutting parameters used.

The effect of cutting speed on the life aspects of a PCBN cutting tool in hardened steel turning has been addressed by Kundrák et al. [17] and Zhao Ch. et al. [19]. In their research, he came to the knowledge that as the cutting speed decreases, the material process of breaking off becomes more and more intense, deteriorating the working surface of the cutting tool more and more.

The problem of microgeometry of machined surfaces by finishing turning and grinding was also dealt with in their research by the team of authors Kundrák et al. [18]. This comparative study analyzed the roughness and accuracy from just 2D and 3D microgeometric point of view on 20MnCr5 steel. The machining allowances were removed by turning, grinding and the combination of them. It was found that, except for the turning process carried out at the highest feed rate, in the four procedure versions nearly identical surface roughness values can be reached.

Investigated materials M390 and M398 are produced by HIP method as a primary producing method, therefore their properties are special ab inito. Their producer, company Böhler recommends for the processing own types of cutting inserts, but of course, list also an international standard in ISO Grade. Producer in catalogue presents more types of material processing. Due to using of the turning only its parameters will be mentioned. The main goal of this research with using selected an experimental methods and manufacturer´s recommendations is to determine optimal parameters for processing of both materials with accessible cutting inserts and evaluate after the processing the surface topography, surface roughness *Ra* (μm) and after then analyse the chip formation in the investigated process of hard turning. Altogether it is important to compare parameters between M390 and M398 due to slightly different properties of M398. Aiming of this research leads to plastic industry, especially to production of screws for injection moulding machines. The M390 is actually used as a material for this type of component and M398 is a new generation from reliable supplier which is offered as an improved alternative to M390. By that it is necessary to compare both materials, if the parameters are equal, or if it will be necessary to change the processing parameters of working machine after the switch to new material. The assumption is, that M398 processing would be more difficult than M390.

In summary, based on the analysis of the authors who have dealt with and solved the subject in their research, it can be stated that the microgeometrical aspect in combination with the analysis of the chip after machining represents an important insight into the machining process of the steels under study, and the process of this research is far from being completed at present. Therefore, the authors of this article also aimed to partially extend the knowledge in the field, as well as to explore the possibilities of machining these PM steels with regard to industrial practice.

2 Materials and methods

Examined steels Böhler M390 Microclean® and M398 Microclean® are martensitic chromium steels which both have high range of alloy components, mainly Chrome [4, 5]. These steel alloys regarding their content do not have equivalent in the standards ISO, EN and others, but it is possible to assign them to group of highest quality high speed steels. For its properties the steels are used mainly for processing of plastic materials with abrasive fillers as glass fibres and also materials with aggressive chemical components as

Chlorine (PVC) or Suplhur (PES). Both investigated steels are produced by HIP method as was mentioned before in the introduction part of this article, where the liquid material is atomized by inert gas.

Chemical composition of these examined steels can be seen in Tab. 1 and Tab. 2, which contains data provided by the manufacturer and which are also compared with the result of the spectral analysis carried out by the authors on the SPECTRO measuring device. Such properties predispose M390 steel to the manufacture of screws for injection moulding machines, which are thermally and mechanically stressed in chemically aggressive environments during their production operation. Intermetallic M398 is therefore also a potential replacement for M390 steel.

Tab. 1 *Comparison of the chemical composition of M390 material (wt. %)*

Chemical content of M390 according to Microcelan® and spectral analysis measurement							
Component	C	Si	Mn	Cr	Mo	V	W
Content % Böhler	1.9	0.7	0.3	20.0	1.0	4.0	0.6
Content % Spectro	1.98	1.19	0.38	20.37	0.85	4.02	0.33

Tab. 2 *Comparison of the chemical composition of M398 material (wt. %)*

Chemical content of M390 according to Böhler Microcelan® and spectral analysis measurement							
Component	C	Si	Mn	Cr	Mo	V	W
Content % Böhler	2.7	0.5	0.5	20.0	1.0	7.2	0.7
Content % Spectro	2.65	0.55	0.51	20.09	1.0	7.1	0.43

Placement of additional components increases anti abrasive properties of material, as was mentioned in article of A. Blutmager et al. [6], abrasive influences affect mainly the base material matrix, while additional components, mostly as carbide forms maintain their position as long as possible, therefore they act like a resistance against cutting tool also in base – Ferritic state of matrix.

In the process of experiments, measurements of basic mechanical properties of the investigated intermetallic PM steels were carried out. The Brinell hardness in the as-delivered condition was 280 HB for M390 and 330 HB for M398. Among other physical properties, M390 has a density value at 20°C equal to 7.54 kg.dm^{-3} and M390 equal to 7.46 kg.dm^{-3}.

The advantage of this powder metals production technology is that thanks to removing of the gas and high pressure during the process material is not porrous what ensures its excelent mechanical properties. By the temperature lower than solidus the powder grains are not fully melted and the junction of material grains is provided by melted surface of powder grains. Both materials contain high volume of alloy components which are occurred in the matrix as carbides. These components helps material to get excellent results which predestinates it for use in very hard conditions. The M398 PM steel is new generation from the same producer, company Böhler. According to available information it has better resistance against wear and slightly lower but still comparable resistance against chemical influences.

Within the frame of material research, it was realized LM (Light Microscopy) and SEM (Scanning Electron Microscopy) observation. The reason was simple in order to find out how the microstructure looks like and also if the different content of components will have an effect on different microstructure.

Based on Fig. 1a, b, both materials seem to be visually similar. M398 has higher range of alloy components as M390 (32,6% / 28,5%) and it is possible to assume that range of lighter fields at M398 is bigger than at M390. Darker fields are basic material (Ferrite), while lighter fields are alloy components, mostly carbides. Visual aspect confirms the data about the content from producer of materials, where M398 contains higher amount of additional components as M390. At the same time, it is possible to see how fine the structure of material is.

At 1000 multiplied magnification it is not possible to recognize more than light and dark points. Due to that fact it will be necessary to analyse materials by the scanning with using the SEM method. Therefore, a microstructural analysis of the SEM was also observed, which was carried out by part of the current author's team and published in the paper [11]. Therefore, this article and performed research also builds on previous experiments in this area of intermetallic PM steels and continues with the technological part of the research.

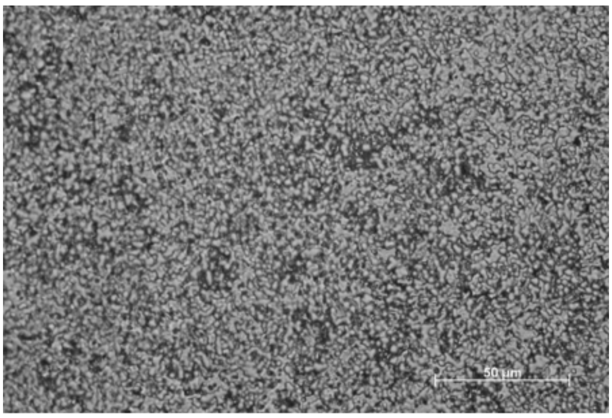

Fig. 1a *LM microstructure of material M390*

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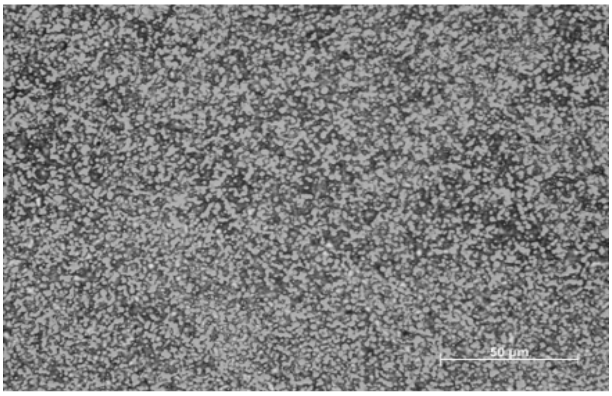


Fig. 1b *LM microstructure of material M398*

In addition to martensite, the microstructure also contains residual austenite that the exact amount has not been evaluated. A detailed examination of the SEM microstructure (Fig. 2a, b) of both investigated PM steels confirmed the presence of carbides M_7C_3 and MC based on Chromium and Vanadium, as can be seen in Fig. 2a, b.

As a preparation for experiment, the LM and SEM microstructure analysis, chemical composition and mechanical properties analysis of both materials was made to find out the status of tested materials, or more precisely to prove information from material supplier.

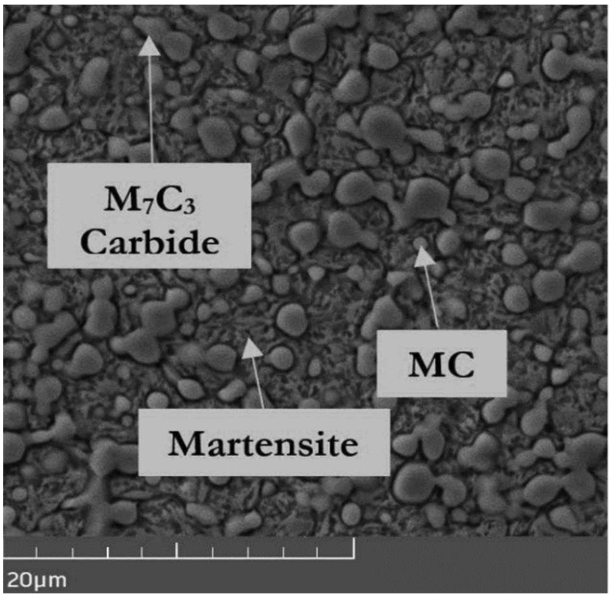


Fig. 2a *SEM microstructure of M390 steel [11]*

Machining experiment was performed in the CNC machine tool AERO MT 300L with control system FANUC Series Oi-TC (Fig.3a). By programming the testing surface on the workpiece, this experiment was divided for nine sections of 10 mm wide, between it was a neck-downs 3 mm wide. By the neck-downs the single sections were separated to prevent indefinites and ambiguity during following measurement of surface roughness.

When processing of sections was finished, the surface roughness Ra value was measured. Processing by another type of cutting insert followed with the same operation order for all 9 segments and final measurement of the surface roughness *Ra*. Thus, all the cutting inserts were alternated. The same processing was applied for both materials M390 and M398. Processing was planned without coolant with following measuring of the surface roughness for each section and collecting of the chips for later analysis. Measuring of surface roughness was performed three times for each section – workpiece was turned by approx. 120° before each measuring.

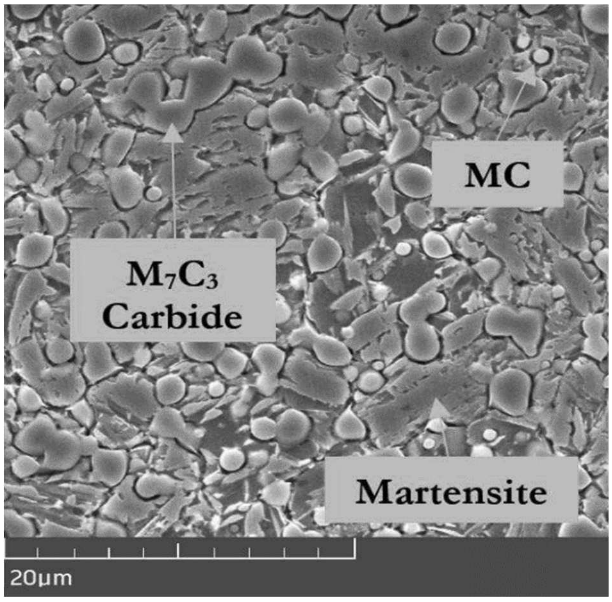


Fig. 2b *SEM microstructure of M398 steel [11]*

This way it was chosen to prove measured average values of roughness with rounding to two decimal places. Later photo shooting of chips was done by Olympus OMD-EM1 Mk.III camera with M. Zuiko Digital ED 60MM F2.8 Macro lens with aperture set to f 8.0. For processing of surface, the cutting inserts from producer DormerPramet were chosen, specifically DNMG 110408E-NMR T9315, DNMG 110404E-M T9315, WNMG 080408E-NF T9315 and WNMG 080404E-NF T9315.

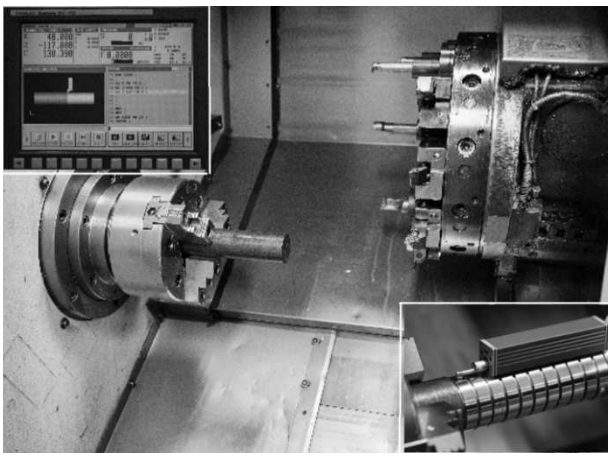


Fig. 3a *Machining process and roughness measurement setup*

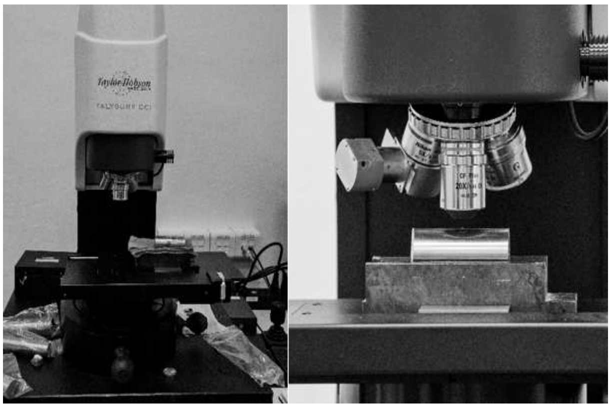


Fig. 3b *Surface topography, roughness and accuracy experimental setup*

As mentioned above, these types of cutting inserts were advised by their producer, company DormerPramet as a most suitable for processing of powder metallurgy steels M390 and M398.

To receive more precise result of the surface roughness, Taylor Hobson Talysurf CCI coherent correlation interferometric microscope (Fig. 3b) was used to evaluate it in laboratory conditions. Only 6 samples were at disposal after the tests, so only WNMG geometry was chosen for this measuring and damaged surface of M398 processed by DNMG 110404E-M to visualize the difference between standard and damaged surface after the processing.

During the experiments the chip samples were collected for later analysis and preparation of chip diagrams. Based on the range of the tests and striving for choosing of similar parameter the chip produced at v_c = 225 m.min^{-1} and at every value of the feed was chosen. Seeing that cutting speed and also the feed for M398 was at last two experiments modified, simultaneously at experiment the cooling by coolant was used, it was decided that this chip will be not collected, because its comparison with the others based on different parameters and enormous influence of coolant is not relevant.

3 Results and discussion

The goal of this experiment was to achieve knowledge about processing of powder metallurgy produced PM materials M390 and M398 from company Böhler [4, 5] by recommended cutting insert from company DormerPramet. Demanded data, or output was surface roughness Ra produced by several cutting inserts at three different cutting speeds and feed rates. The one and only constant value was the depth of cut a_p = 1 mm. For evaluation of results two types of graphical dependences were chosen a graph of dependency of surface roughness from feed rate f [mm] and graph of dependency of surface roughness Ra [μm] from cutting speed v_x [m.min^{-1}], which optimally represents measured values.

The performed experiment shows that the feed rate *f* had the highest influence for the surface roughness *Ra* of processed sections. Furthermore, the higher the feed rate *f* value was, the higher value of surface roughness *Ra* was measured. Feed rate had similar influence for each applied cutting speed in realized process of hard turning experiment.

For better comparison of dependencies of surface roughness *Ra* from the feed rate *f*, combined graphs were made (see Fig. 4a, b), which compares behaviour of roughness processed by cutting insert DNMG 110408E-NMR T9315 and WNMG 080408E-NF T9315 for M390 and M398 steels.

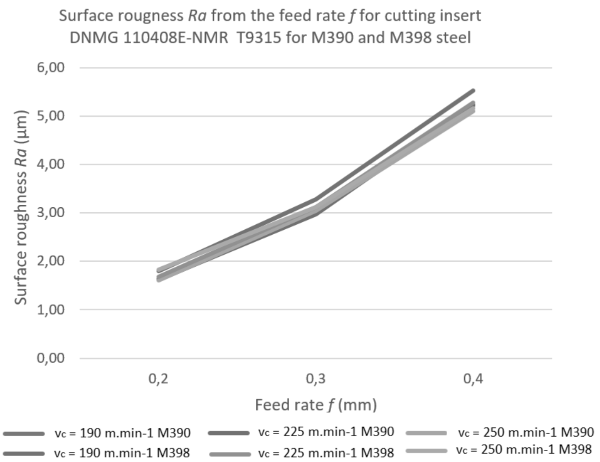


Fig. 4a *Graphical comparison M390 and M398 steels in use of cutting insert DNMG 110408E-NMR T9315 geometry*

From the same reason, therefore for easier comparison a combined graph was made for comparison of dependencies, which compares behaviour of surface roughness *Ra* processed by cutting insert WNMG 080408E-NF for M390 and also M398 steel (see Fig. 4b).

As it is visible from the Fig. 4a, b, the feed rate value *f* = 0.3 mm is properly chosen for processing of M390 and M398 materials from the perspective of surface roughness. For the feed rate *f* = 0.2 mm a scattering at different cutting speeds was visible (especially for WNMG 080408E-NF), nevertheless at feed rate *f* = 0,4 the roughness behaviour was almost the same, but in comparison with other feed rate the surface roughness was too high.

This part of the performed experiment indirectly proved higher mechanical properties (hardness and resistance against wear), or rather higher ratio of additional components, influencing the machinability of PM steel M398, because the base matrix of both processed materials is Ferrite. In case of M390 it was not necessary to modify the cutting parameters either at cutting speeds (see Fig. 5a, b, and also Fig. 6a, b) in which for M398 the cutting insert and material surface degraded.

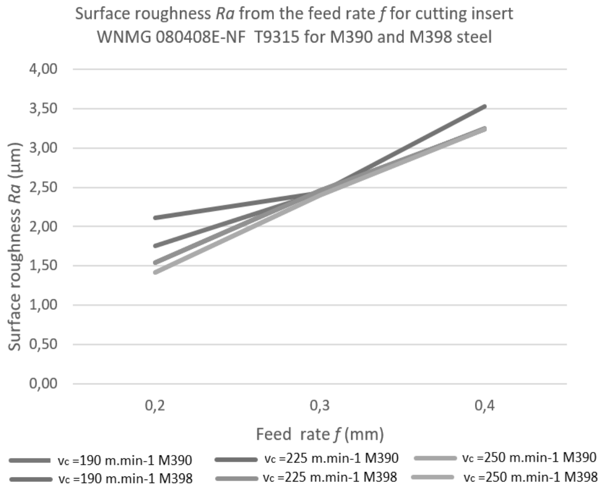


Fig. 4b *Graphical comparison M390 and M398 steels in use of cutting insert WNMG 080408E-NF T9315 geometry*

The M390 and M398 steels were indirectly compared, but the performed experiment proves information from supplier, which for M398 recommends using lower cutting speeds as for M390 steel.

Contrariwise, it is possible to acclaim that higher feed rate had clear influence for the increasing roughness. The higher the feed rate value was, the higher value of surface roughness was measured, what comes out of the logic, or rather mechanics of cutting movements functioning, when the tip of the cutting tool during the faster movement is leaving deeper imprint, because the feed speed does not allow to cut down the sides of previous imprints and therefore the Rz values are higher, what causes increasing of the arithmetic average of profile height deviation line – Ra, because the maximum values of peaks and valleys are higher than at lower feed value.

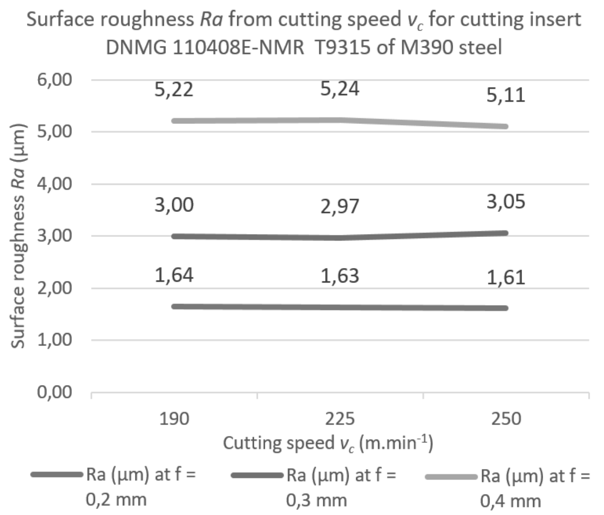


Fig. 5a *Graphical dependency of surface roughness Ra from the cutting speed v_c for cutting insert DNMG 110408E-NMR for M390 steel*

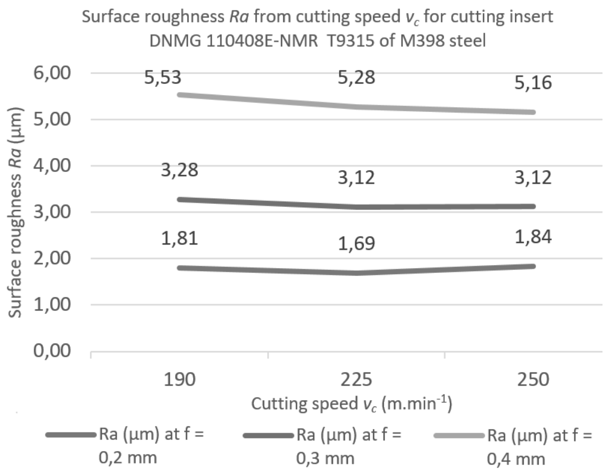


Fig. 5b *Graphical dependency of surface roughness Ra from the cutting speed v_c for cutting insert DNMG 110408E-NMR for M398 steel*

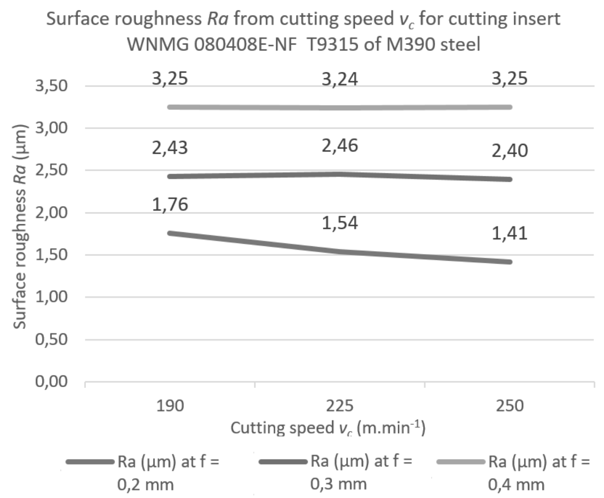


Fig. 6a *Graphical dependency of surface roughness Ra from the cutting speed v_c for cutting insert WNMG 080408E-NF for M390 steel*

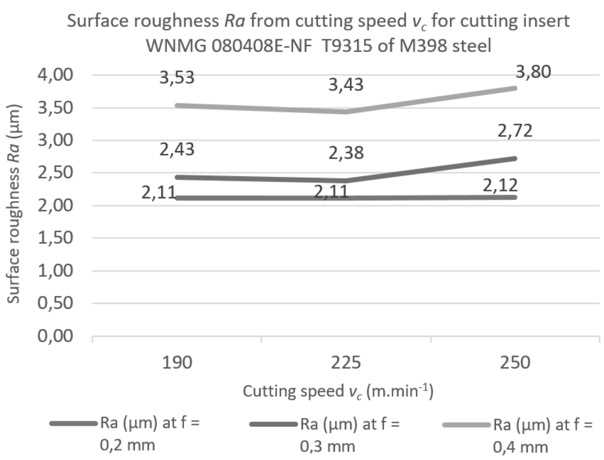


Fig. 6b *Graphical dependency of surface roughness Ra from the cutting speed v_c for cutting insert WNMG 080408E-NF for M398 steel*

To receive more precise results of the 2D surface roughness (see Tab. 3) and 3D surface topography, (see Fig. 7a, b, Fig. 8a, b, and Fig. 9), Taylor Hobson Talysurf CCI coherent correlation interferometric microscope (see Fig. 3b) was used to evaluate it in laboratory conditions. Only 6 samples were at disposal after the tests, so only both WNMG geometry was chosen for this measuring and also damaged surface of M398 processed by DNMG 110404E-M geometry in order to visualize the difference between standard and damaged surface after the hard machining process. From the results measured by Taylor Hobson Talysurf, it is visible that the surface roughness of M390 was lower that at M398 in case of *Ra* and *Rz*, too.

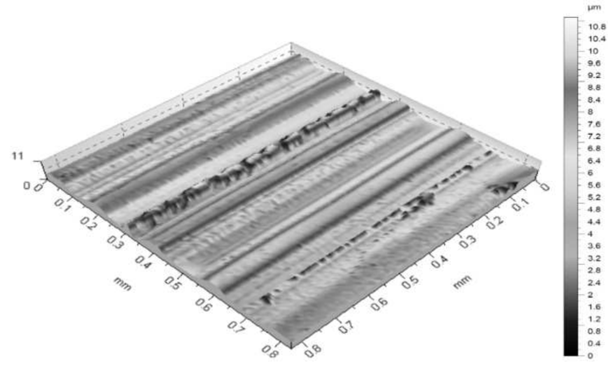


Fig. 7a *Surface topography for M390 steel processed by WNMG 080408E-NF T9315 geometry of cutting insert*

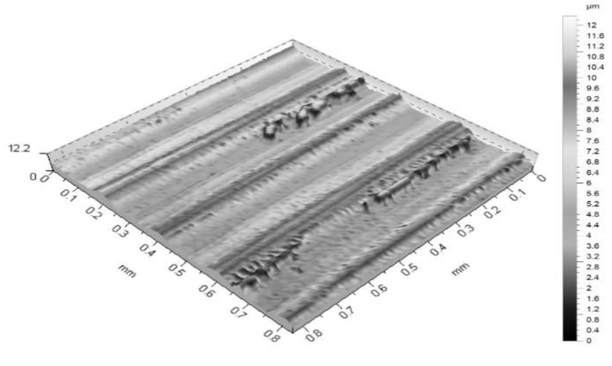


Fig. 7b *Surface topography for M398 steel processed by WNMG 080408E-NF T9315 geometry of cutting insert*

At M398 we can also see higher fragmentation, it means more left fragments on the surface, what has main influence for *Rz*, but at the end also for *Ra*. The lowest surface roughness was measured by both methods – measuring at the workshop (Mitutoyo SJ-301) and laboratory (Taylor Hobson Talysurf CCI) for cutting insert WNMG 080408E-NF. Profile of M398 steel after the degradation of cutting insert DNMG 110404E-M (see Fig. 9) is visibly rougher than at all other cutting inserts (as can be seen in Fig. 7a, b and Fig. 8a, b). The comparison of *Ra* and *Rz* from both of the performed investigations, the laboratory values are lower. The reason should be cleaning of surfaces before measuring by Taylor Hobson Talysurf CCI, but also its higher precision and stable conditions in laboratory. Even that the results are more less corresponding with the trend measured by Mitutoyo SJ-301.

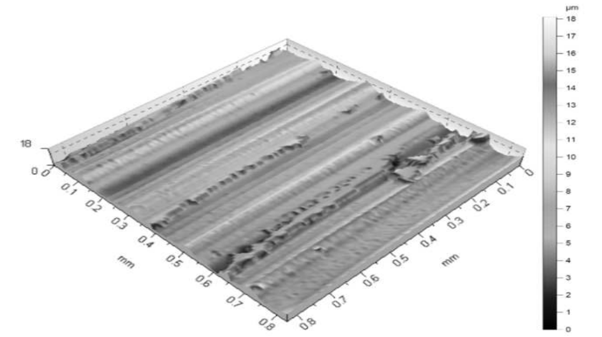


Fig. 8a *Surface topography for M390 steel processed by WNMG 080404E-NF T9315 geometry of cutting insert*

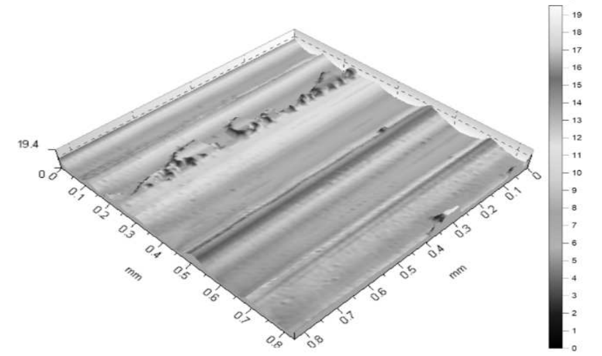


Fig. 8b *Surface topography for M398 steel processed by WNMG 080404E-NF T9315 geometry of cutting insert*

At comparable experiments, it means by using of DNMG 110408E-NMR T9315 and WNMG 080408E-NF T9315 geometry of changeable cutting insert for turning of both PM steels, the M390 steel showed lower surface roughness after machining than M398 steel (see Fig. 4a, b). Differences of the surface roughness were not too big, there was a difference only few tens of micrometers (µm), but still the differences are visible. Higher resistance against machining and by that higher surface roughness confirms information from producer regarding higher hardness of material M398 (as also can be seen in Fig. 10).

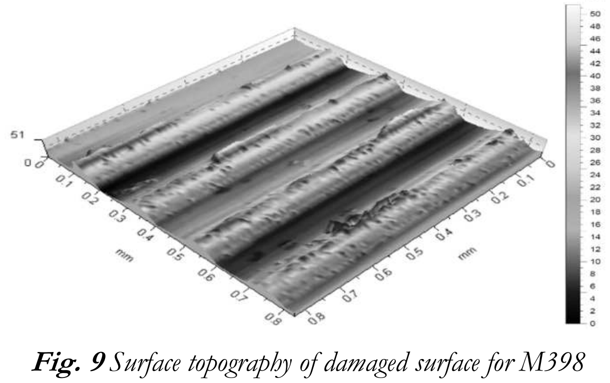
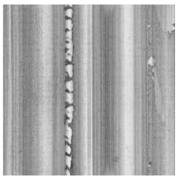
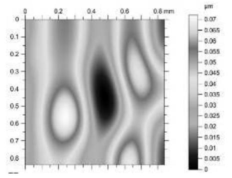
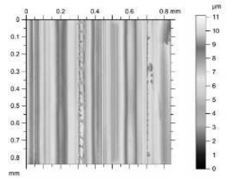
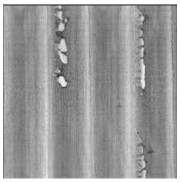
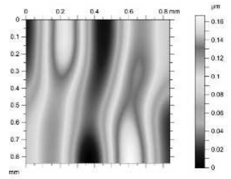
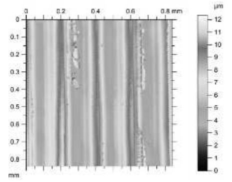
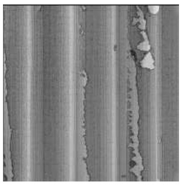
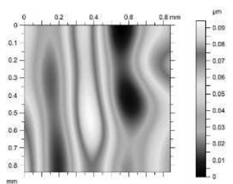
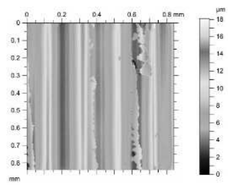
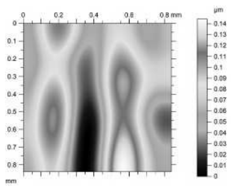
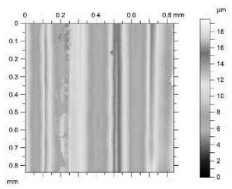
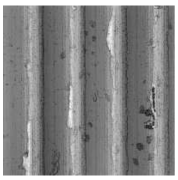
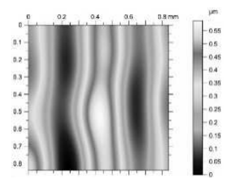
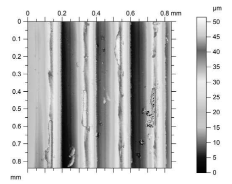


Fig. 9 *Surface topography of damaged surface for M398 processed by DNMG 110404E-M T9315 geometry of cutting insert*

***Tab. 3** Achieved results of the microgeometrical characterisstics of investigated machined surface*

Topogr. Fig.	*2D parameters of roughness*	*Amplitude parameters*	*Surface texture*	*Surface waviness*	*Surface roughness*
Fig. 7a	*Ra* = 1.211 μm	*Sa* = 1.289 μm			
Fig. 7a	*Rq* = 1.462 μm	*Sq* = 1.552 μm			
Fig. 7a	*Rz* = 6.026 μm	*Sz* = 10.08 μm			
Fig. 7a	*Rt* = 6.459 μm	*St* = 11.11 μm			
Fig. 7a	*RSm*=0.07948mm				
Fig. 7b	*Ra* = 1.633 μm	*Sa* = 1.639 μm			
Fig. 7b	*Rq* = 1.867 μm	*Sq* = 1.894 μm			
Fig. 7b	*Rz* = 7.049 μm	*Sz* = 11.62 μm			
Fig. 7b	*Rt* = 7.709 μm	*St* = 12.35 μm			
Fig. 7b	*RSm* =0.1295 mm				
Fig. 8a	*Ra* = 1.933 μm	*Sa* = 2.022 μm			
Fig. 8a	*Rq* = 2.286 μm	*Sq* = 2.431 μm			
Fig. 8a	*Rz* = 9.052 μm	*Sz* = 14.14 μm			
Fig. 8a	*Rt* = 9.532 μm	*St* = 18.11 μm			
Fig. 8a	*RSm* = 0.1320mm				
Fig. 8b	*Ra* = 2.119 μm	*Sa* = 2.212 μm			
Fig. 8b	*Rq* = 2.524 μm	*Sq* = 2.671 μm			
Fig. 8b	*Rz* = 9.578 μm	*Sz* = 13.59 μm			
Fig. 8b	*Rt* = 11.31 μm	*St* = 19.54 μm			
Fig. 8b	*RSm* = 0.1468mm				
Fig. 9	*Ra* = 8.383 μm	*Sa* = 8.683 μm			
Fig. 9	*Rq* = 10.01 μm	*Sq* = 10.43 μm			
Fig. 9	*Rz* = 40.70 μm	*Sz* = 49.97 μm			
Fig. 9	*Rt* = 45.10 μm	*St* = 51.54 μm			
Fig. 9	*RSm* = 0.1530mm				

Where:

Ra…Arithmetic Mean Deviation of the roughness profile,

Rq…Root-Mean-Square (RMS) Deviation of the roughness profile,

Rz…Maximum Height of roughness profile,

Rt…Total Height of roughness profile,

RSm…Mean Width of the roughness profile elements,

Sa…Arithmetic mean deviation,

Sq…Root mean square mean deviation,

Sz…Ten-point height,

St…Total height.

For processing of material M398, it is also suitable to use coolants for cutting, and also improvement of cutting parameters, what results from the experiments where without coolant occurred rapid degradation of cutting insert and material surface. Producer of material also recommends using of coolants for both materials.

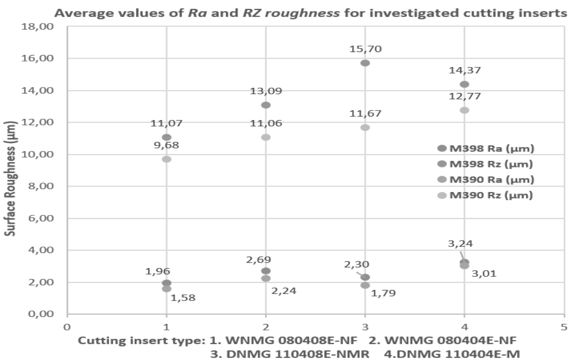
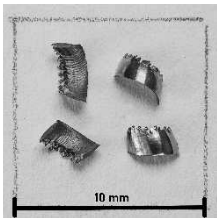
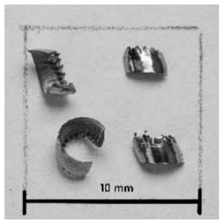
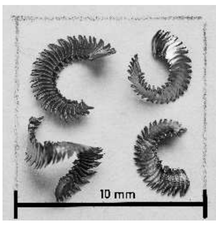
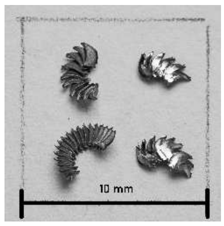
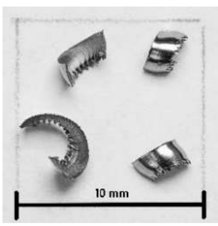
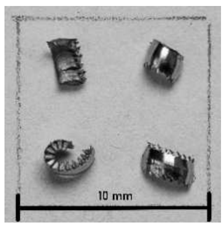
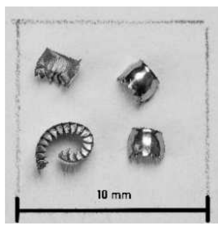


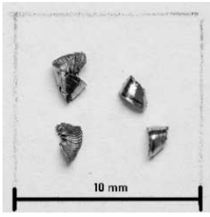
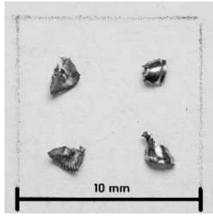
Fig. 10 *Graph of average values of roughness Ra and Rz for M390 and M398 steels after using all types of cutting inserts in a process of performed investigation*

During the running process of realized experiments the chip samples were separated for later analysis and preparation of chip diagrams. Based on the range of the tests and striving for choosing of similar parameter the chip formed at v_c = 225 m.min^{-1} and at every value of the feed rate was examined. Seeing that cutting speed and also the feed rate for M398 was at last two experiments modified, simultaneously at experiment where the coolant was used, it was decided that this chip will be not investigated, because its comparison with the others based on different cutting parameters and enormous influence of coolant is not relevant for the investigation.

Tab. 4 *Comparable chip diagram for M390 and M398 steels by using a geometry of cutting inserts DNMG 110408E-NMR T9315 and WNMG 080408E-NF T9315 in the machining*

Chip diagram for cutting speed 225 m.min^{-1} for M390 and M398 steels				
		Feed rate *f* (mm)		
Type of cutting insert	Material	0.2	0.3	0.4
DNMG 110408E-NMR T9315	M390			
	M398			
WNMG 080408E-NF T9315	M390			
	M398			

Tab. 5 *Comparable chip diagram for M390 steel by using a geometry of cutting inserts DNMG 110404E-NMR T9315 and WNMG 080404E-NF T9315 in the process of machining*

Chip diagram for cutting speed 225 m.min^{-1} for M390 steel				
		Feed rate *f* (mm)		
Type of cutting insert	Material	0.2	0.3	0.4
DNMG 110404E-M T9315	M390			
WNMG 080404E-NF T9315	M390			

The first chip diagram (see Tab. 4.) represents comparison of chips between machined material M390 and M 398 at cutting speed v_c = 225 m.min^{-1}, at the feed rate *f* = 0.2 mm, *f* = 0.3 mm, *f* = 0.4 mm and with using a geometry of changeable cutting inserts DNMG 110408E-NMR T9315 and WNMG 080408E-NF T9315.

The second chip diagram (see Tab. 5) represents comparison of chips of machined material M390 at cutting speed v_c = 225 m.min^{-1}, at the feed rate *f* = 0,2 mm, *f* = 0.3 mm a *f* = 0,4 mm and with using a geometry of changeable cutting inserts DNMG 110404E-M T9315 and WNMG 080404E-NF T9315. From the chip diagram (Tab. 5.), or rather from the chip analysis results that for both materials (M390 and M398), and also for both used cutting inserts (DNMG 110408E-NMR T9315 and WNMG 080408E-NF T9315) the chip is cut and segmented, according to [19], what means that the chip is smooth from the rake face of cutting insert, because tangential strains are higher than normal strain, but also the chip is divided to segments. This type of chip is characteristic for tough materials and machined surface is smoother as for torn chip.

In the chip diagram differences between materials are visible. The chips of material M390 are segmented, but mostly to the centre in accordance with direction, which is not in contact with the cutting segment, but they make nearly fully continuous surface. The chips of material M398 are segmented, also, but in their case the chip has smaller central continuous surface, and it is separated around the edge, you could say that it is fan-shaped.

After the machining process of M390 PM Steel by cutting inserts DNMG 110404E-M T9315 and WNMG 080404E-NF T9315, so there is visible different shape of the chips as can be seen in Tab. 5. The main reason is lower tool apex diameter. (0.4 vs. 0.8 mm) and different geometry of the chip shaper of cutting insert DNMG 110404E-M T9315. Also, in this case the chip is cut segmented, but the first type of cutting insert with cut shaper type “M” created smaller, or rather shorter chip as the cutting insert with radius 0,8 mm (WNMG 080408E-NF T9315), but also this chip was smaller, similar as DNMG 110404E-M T9315, what is caused most probably by the tool apex diameter 0,4 (in comparison with 0.8 in Tab. 5).

Overall, we can state that shapes of all chips are convenient, except for those which were made during the production of the neck-downs. During the production of neck-downs is the production of long continuous chip common. Neck-downs were not made by mentioned cutting inserts, therefore the shape of this chip is irrelevant in this case.

4 Conclusions

Component failure, fatigue and corrosion processes usually start on or just below the machined surface. It is therefore increasingly necessary to study the nature of the formation of a new surface and to explain or extend the already acquired knowledge of the influence of the cutting process on the properties of the newly formed surface.

Micro-uniformities are created on the machined surface. The thin layer beneath the machined surface is deformed by the force effect of the working tool during machining. As a result of the deformation and heating of the surface layer by the heat that always accompanies the machining process, stresses are formed in this layer and its physical-mechanical properties change. The values of surface quality indicators of machine parts must be sought in the production technology itself, especially in machining. From the experiment performed during the processing and also from the comparison of the chip results that both materials are demanding to machining in delivered state. More demanding properties for machining has material M398 which is harder than M390. In the state of the material after thermal processing it is advisable to perform only the finishing operations to get status of surface with very high surface integrity, which ensures long life of injection moulding machine screw.

Properties of both materials are significantly affected by their content and by the method of their production (HIP). The process temperature during the HIP process is around 0.8 of melting temperature [11], with the simultaneous application of the high pressure, at the same time there are more or less deployed oxides of additional components which are very hard and during following machining they resist altogether with tough Ferritic matrix. Just the Chromium content 20% [4 - 5] shows that these materials are not simply and easily machined, because one of the Chromium functions as an additional component is to increase resistance against wear. By the HIP method, a high compact material structure is achieved without unnecessary defects as various dislocations, internal cavities, cracklings, or material porosity, which is common for some other production methods of powder steels.

All performed experiments & investigations confirmed assumptions, also the information from producer and thanks to this it is now possible to determine suitable processing parameters to achieve the best surface roughness before finishing operations and at the same time to prevent material suffer and its surface negative affecting by inappropriate machining parameters.

The task of surface integrity research is to generate new theories in the light of current trends in technological practice, i.e. to improve, from a qualitative point of view, the functionality of the surfaces of components. In engineering practice but also in the scientific spectrum, this concept accompanies the component throughout the manufacturing process. Therefore, in the practical conditions, and also with the summary findings from all performed experiments & investigations of production of machinery and special equipment, the following theses can be drawn:

- Surface integrity is significantly influenced by the sequence of manufacturing operations given by the technological process, but the initial operations, sometimes called roughing operations, have less influence on the technological inheritance of functional surfaces than finishing operations.
- When machining M390 as well as M398, the feed rate has the highest effect on surface roughness. Also when the lower feed rate is, the lower surface roughness is then achieved.
- Cutting speed affects the surface roughness only minimal, without any visible trend.
- The radius of the tool tip also affects the resulting surface roughness *Ra*. With a radius of 0.4 mm, the surface roughness was higher than with a radius of 0.8 mm.
- PM steel M398 is harder and more difficult to machine than M390 steel, mainly due to higher content of additional components, because the basic matrix is the same – Ferrite. The components – carbides cause higher resistance against machining and higher tool wear as can be seen in Fig. 9.
- For processing of both materials, it is suitable to use coolants as is recommended by material producer, especially for M398 steel machining it is more than needed.
- Chips at the set cutting parameters were appropriately shaped for both materials, even if they had slightly different shapes for M390 and M398 steel.
- Due to the properties of the materials in their delivered state, it is advisable to perform all essential machining operations before heat treatment of the material and only to perform minor finishing operations afterwards.
- In order to be able to successfully address complex indicators of surface quality and functionality, it is necessary to know and be able to practically apply the laws of surface integrity to a sufficient extent, which is also a benefit from the experiments carried out in terms of expanding the knowledge in the field of science.

The all achieved results contributed to the expansion of knowledge about the machining of M390 and M398 materials and contributed to their practical use. From the practical point of view, the research carried out by the authors has undeniably expanded the knowledge about the machining of the steels studied, since there is insufficient research on these types of steels and also in view of the fact that M398 is a new type of material, not yet sufficiently researched and also not yet sufficiently verified in practice. Experiments on the mentioned materials will continue, so that the knowledge of the processing of these materials will help to improve the machining conditions, as well as the efficiency of the entire machining process. The scientific contribution of the experiments carried out is that it extends the knowledge in the field of hard turning with dry turning and cooling to a wider range of machined hardened, but in particular it extends the knowledge in the field of integrity of machined surfaces to PM steels as well. It opens the way for further research in this field, which will enable the optimization of machining processes of hardened components in the production of their dominant functional surfaces. It can be realistically assumed that the development of methods and means of direct monitoring, as well as modelling of functional surfaces in hardened steels, will bring about a further increase in the operational reliability and durability of machine and plant components.

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