ISSN: 1231-4005
e-ISSN: 2354-0133
DOI: 10.5604/01.3001.0012.4778

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

Tomasz Cyryl Dyl

Gdynia Maritime University
Faculty of Marine Engineering
Department of Marine Maintenance
Morska Street 81-87, 81-225 Gdynia, Poland
tel.: +48 58 5586432, fax: +48 58 5586399
e-mail: dylu@am.gdynia.pl

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, then 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 fulfil 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 mm/rev, depth of cut $a_p = 0.5$ mm, cutting speed $v_c = 50$-100 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 μm. 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_2O_3/TiN (2 μm/1.5 μm/2 μm) [20].

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

Insert Shape	Insert Type	Insert Grade	Nose Radius [mm]	Flank Angle [°]	Rake Angle [°]
CC09T3	CCMT 09T308-MM	2025	0.8	7	7
CC09T3	CCMT 09T308-UM	2025	0.8	7	6
CC09T3	CCMT 09T304-UM	2025	0.4	7	6

The tools are characterized by the following features: tool cutting edge angle κ_r= 90º, tool included angle ε_r = 80º, rake angle γ= 6-7º, flank angle α= 7º, nose radius r_ε= 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:

$$L_{SC} = \frac{\Pi\, D_m\, l_m}{f}, \tag{1}$$

where:
D_m – the diameter of the workpiece in the machined surface, [mm], ϕ 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]

C [%]	Cr [%]	Ni [%]	Mo [%]	Cu [%]	Mn [%]	N [%]	Si [%]	S [%]	P [%]
0.024	25.62	6.52	2.98	2.55	0.97	0.25	0.86	0.010	0.008

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 300ºC to 800ºC.

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. Ra is the arithmetic mean roughness value from the amounts of all profile values. Rz 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

No of Samples	Insert Type and Grade	v_c [m/min]	f [mm/rev]	a_p [mm]	Rz [µm]	Ra [µm]	K_{Ra} [–]
09T308-MM-100	CCMT 09T308-MM 2025	100	0.2	0.5	9.19	1.93	1.71
09T308-MM-70	CCMT 09T308-MM 2025	70	0.2	0.5	8.41	1.54	2.14
09T308-MM-50	CCMT 09T308-MM 2025	50	0.2	0.5	11.97	2.31	1.43
09T308-UM-100	CCMT 09T308-UM 2025	100	0.2	0.5	7.55	1.53	2.16
09T308-UM-70	**CCMT 09T308-UM 2025**	**70**	**0.2**	**0.5**	**7.44**	**1.55**	**2.13**
09T308-UM-50	CCMT 09T308-UM 2025	50	0.2	0.5	7.95	1.63	2.02
09T304-UM-70-2	CCMT 09T304-UM 2025	70	0.2	0.5	13.85	3.03	1.09
09T304-UM-70-1	**CCMT 09T304-UM 2025**	**70**	**0.1**	**0.5**	**5.28**	**1.03**	**3.21**

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 Ra = 1.55 µm, while the maximum height of profile is equal to Rz = 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).

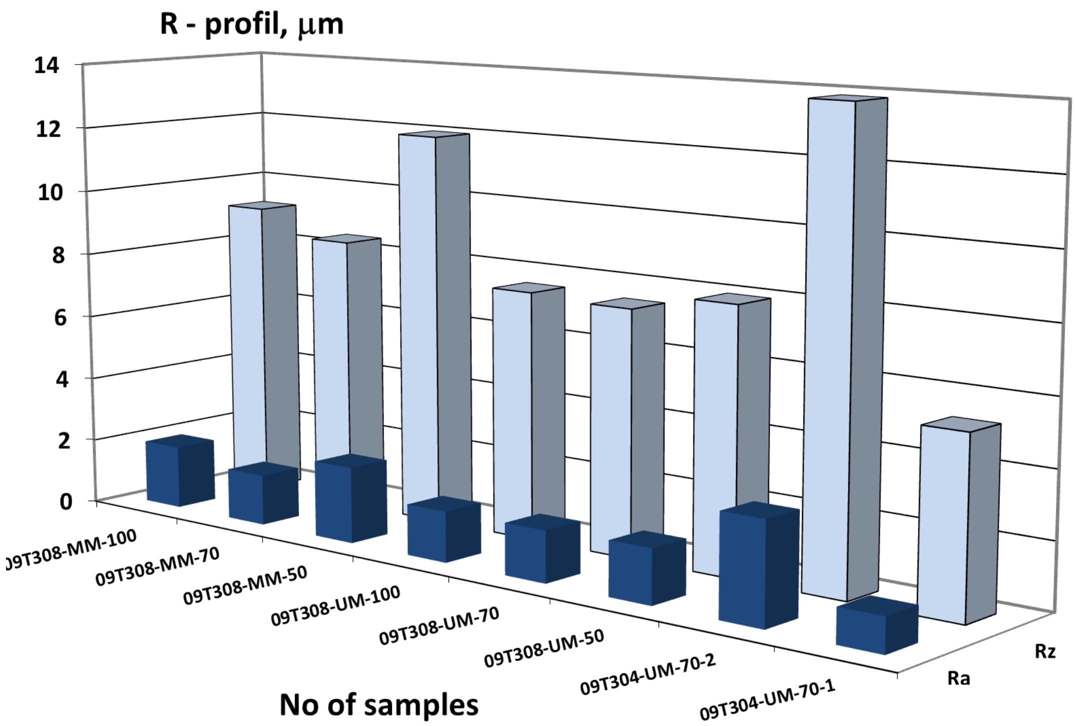

Fig. 2. The arithmetical mean deviation (Ra) and the maximum height of profile (Rz) of the samples turned by the program included in Tab. 3

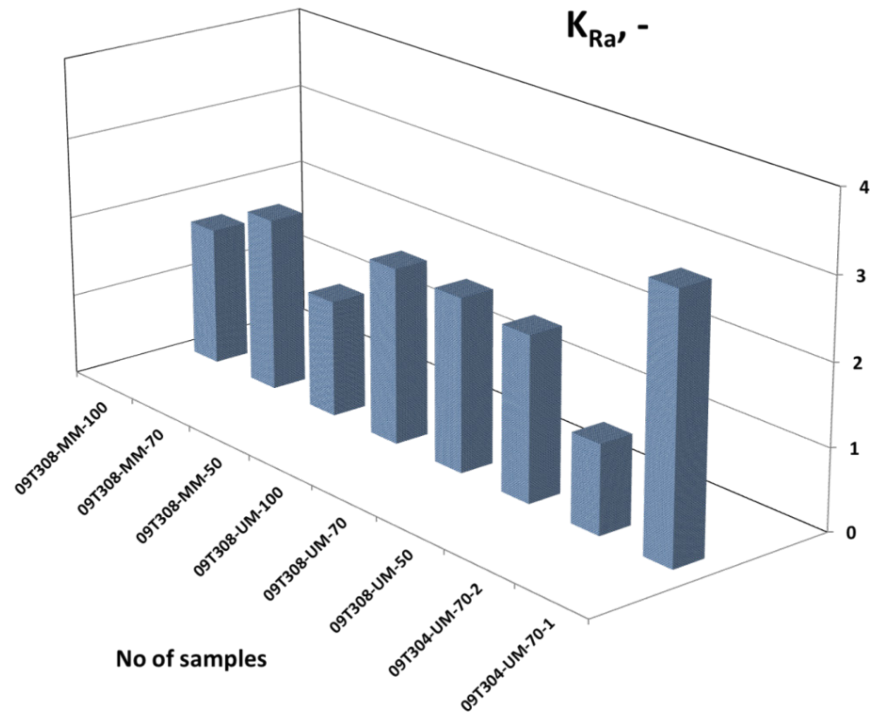

Fig. 3. The surface roughness reduction ratio (K_{Ra}) after turned samples according to the research program in Tab. 3

After the analysed of 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.

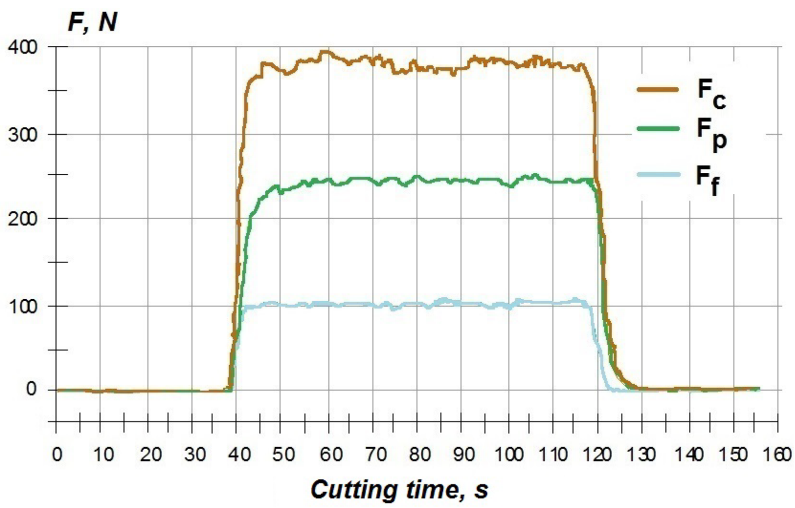

Fig. 4. The typical course of the cutting forces after longitudinal turning for insert CCMT 09T308-UM 2025 for the shaft with cast steel duplex GX2CrNiMoCuN 25-6-3-3, f = 0.2 mm/rev, a_p= 0.5 mm, v_c = 70 m/min, Ra=1.55 μm

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 $f = 0.1\text{-}0.2$ mm/rev, depth of cut $a_p = 0.5$ mm, cutting speed $v_c = 50\text{-}100$ 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 $r_\varepsilon = 0.4$ mm with cutting parameters: feed rate $f = 0.1$ mm/rev, cutting speed $v_c = 70$ m/min, depth of cut $a_p = 0.5$ 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 $r_\varepsilon = 0.8$ mm for precision machining, then should be used feed rate $f = 0.2$ mm/rev and cutting speed $v_c = 70$ m/min and depth of cut $a_p = 0.5$ 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: $v_c = 70$ 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.

References

[1] Burakowski, T., Wierzchoń, T., *Surface engineering of metals: Principles. Equipment. Technologies*, Materials Science & Technology, CRC Press LLC, London, New York, Washington D.C. 1999.

[2] Charchalis, A., Starosta, R., *The influence of finishing on the tribological properties of plasma sprayed MMC coating*, Journal of KONES Powertrain and Transport. Vol. 23, No. 1. pp. 91-97, 2016.

[3] Dyl, T., *Numerical and experimental analysis of burnishing process using the theory of elasticity and plasticity*, Monographs, Gdynia Maritime University, Gdynia 2014.

[4] Dyl, T., Starosta, R., *Wpływ geometrii i gatunku płytek skrawających na strukturę geometryczną toczonych powłok stopowych*, Inżynieria Materiałowa, Nr 4 (182), pp. 395-398, 2011.

[5] Dyl, T., Starosta, R., *Określenie wpływu geometrii i rodzaju materiału płytek skrawających na topografię toczonych powłok kompozytowych*, Inżynieria Materiałowa, Nr 6 (190), pp. 701-704, 2012.

[6] Dyl T., Starosta, R., *Improving the quality of technological surfaces of machines of composite coatings*, Journal of KONES Powertrain and Transport, Vol. 21, No. 1, pp. 75-82, 2014.

[7] Dyl, T., Rydz, D., Stradomski, G., *Nagniatanie staliwa typu dupleks w aspekcie zwiększenia twardości i zmniejszenia chropowatości powierzchni*, Zeszyty Naukowe Akademii Morskiej w Gdyni, Nr 100, pp. 76-86, 2017.
[8] Królczyk, G., Legutko, S., Gajek, M., *Predicting the surface roughness in the dry machining of duplex stainless steel (DSS)*, Metalurgija, 52 (2), pp. 259-262, 2013.
[9] Królczyk, G., Niesłony, P., Legutko, S., *Determination of tool life and research wear during duplex stainless steel turning*, Archives of Civil and Mechanical Engineering, Vol. 15, No. 2, pp. 347-354, 2015.
[10] Królczyk, G., Niesłony, P., Legutko, S., Hloch, S., Samardzic, I., *Investigation of selected surface integrity features of duplex stainless steel (DSS) after turning*, Metalurgija, 54 (1), pp. 91-94, 2015.
[11] Labuda, W., *The influence of changing of cutting parameters on temperature and cutting forces during turning process of stainless steel with CCET09T302R-MF insert*, Journal of KONES Powertrain and Transport, Vol. 24, No. 4, pp. 133-140, 2017.
[12] Labuda, A., Dargacz, M., Klecha, M., Kozłowska, S., *Wpływ zmiany kąta przystawienia noża tokarskiego typu wiper na wartość parametrów chropowatości powierzchni czopów wykonanych ze stali austenitycznej*, Zeszyty Naukowe Akademii Morskiej w Gdyni, Nr 91, pp. 64-77, 2015.
[13] Legutko, S.. *Podstawy eksploatacji maszyn i urządzeń*, WSiP, Warszawa 2004.
[14] Legutko, S., Nosal, S., *Kształtowanie technologicznej i eksploatacyjnej warstwy wierzchniej części maszyn*, Ośrodek Wydawnictw Naukowych PAN, Poznań 2004.
[15] Paro, J., Hanninen, H., Kauppinen, V., *Tool wear and machinability of HIPed P/M and conventional cast duplex stainless steels*, Wear, 249, pp. 279-284, 2001.
[16] Ran, Q., Li, J., Xu, Y., Xiao, X., Yu, H., Jiang, L., *Novel Cu-bearing economic al 21Cr duplex stainless steels*, Materials and Design, 46, pp. 758-765, 2013.
[17] Starosta, R., Dyl, T., *Obróbka powierzchniowa*, Wyd. Akademii Morskiej w Gdyni, Gdynia 2008.
[18] Starosta, R., Dyl, T., *Obróbka wykańczająca natryskiwanych płomieniowo powłok Ni-Al. ocena zużycia borazonowych płytek skrawających*, Tribologia. Teoria i Praktyka, Nr 4, pp. 245-252, 2011.
[19] Stradomski, G., *Oddziaływanie morfologii fazy sigma na kształtowania właściwości stali i staliwa duplex*, Politechnika Częstochowska, Częstochowa 2016.
[20] *Turning insert. Tools for metal cutting*, CoroTurn®107, Sandvik Coromant, http://www.sandvik. coromant.com/en-us/products/pages/tools.aspx, 11.05.2018.

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