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Influence of Cutting Conditions in Turning with Wiper Type Inserts on Surface Roughness and Cutting Forces

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In the paper, evaluation of the influence of selected cutting parameters on surface roughness of the workpiece is presented. Conventional geometry and wiper geometry inserts were applied. Relationship between cutting forces levels during turning tests of C45 steel are presented too. Moreover evaluation of experimental results which consider application of different strategies of cutting fluid supply such as wet machining and dry machining are shown. Description of experimental conditions and methodology of investigation are presented. Finally experimental stands which were employed during surface roughness and cutting forces measurements are described too.

Keywords: Turning, cutting force, Wiper geometry

1. Introduction

Modernimprovements in manufacturing processes drive the development of new technologies and means of production, designed to achieve increased productivity and reduced the costs of production while maintaining the high quality of products. In order to increase productivity in this sense, tool manufacturers are continuously improving their materials, offering new coatings for cutting edges and modifying the geometry of cutting inserts.

The measures listed above enable the achievement of better cutting parameters, which results in linear improvement of processing efficiency. However, increasing individual parameters is affected by certain limitations, such as [1]:

- permissible cutting force values, resulting from the specific stiffness or strength of individual elements of the machine tool – workpiece system,
- the accuracy of shape and dimensions of the work surfaces,
- the allowable output power of the machine tool drive unit,
- deteriorating surface roughness or precision of machining,
- inherent strength of cutting inserts.

One solution that enables the application of high–feed cutting inserts whilst maintaining a low surface roughness of the machined surface is the use of superfinishing inserts with wiper geometry [2, 3]. In this type of insert the conventional radial corner has been modified so that the areas of the edge which come into direct contact with the work surface, have a substantially greater corner radius or are rectilinear (Fig. 1). Using a geometry like this at a double feed rate can yield certain parameters of surface roughness on levels achieved when using conventional inserts. The obvious result of this is improved productivity by increasing efficiency and lowering production costs [4].

At the same time, according to data provided by manufacturers [2], processing of a workpiece at a standard feed rate will reduce roughness of the machined surface twofold. As a result, in a number of cases expensive abrasive machining processes can be avoided. Manufacturers of the tools also claim that along with improved smoothness of the machined surface the obtained roundness of the workpiece is comparable to the result of grinding.

Figure 1 shows the shaping of roughness (*Rt* parameter) when machining by means of a conventional tool insert with standard nose radius geometry (a) and a wiper insert (b and c), depending on the value of feed,f.

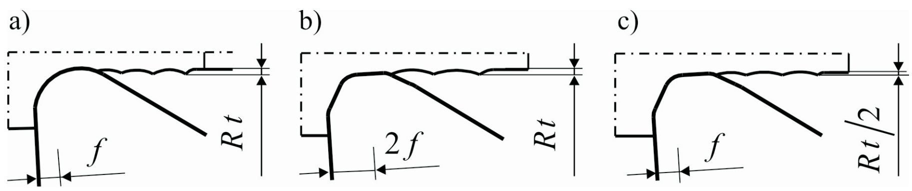

Figure 1 Scheme of surface roughness creation (Rtparameter) during turning process: a) standard nose radius geometry, b-c) wiper geometry

In addition tothe advantages mentioned above, wiper inserts have some drawbacks, which result from their specific geometry. The weaknesses include, for example, the following [1, 5]:

- the inability to provide uniform smoothness of the surfaces which are at different angles in relation to the axis of rotation of the workpiece,

- difficulty in maintaining the accuracy of reproduction of the shape when contour turning complex surfaces,
- they generate a 10–15% higher value of the back force, F_p.

The latter has a clear impact on the cutting process and the accuracy of machining, because a higher back force stimulates vibrations towards the x axis, which – in consequence – may result in dimensional inaccuracy or the distorted shape of the machined piece.

The Institute of Machine Tools and Production Engineering of the Lodz University of Technology performed turning tests in which the performance of wiper inserts was compared with that of radial corner inserts. Both tests were carried out using the following methods of application of cutting fluids:

- wet machining, WM, (where the cutting fluid was supplied in ample quantities), and
- dry machining, DM, (without cutting fluid).

The influence of the method of application of the cutting fluid on components of the total cutting force and surface roughness of the machined surface has been described in the subsequent section.

2. Test conditions

During the tests, samples of C45steel (hardness 230 HB) in a normalised condition were subject to straight turning by means of a Sandvik insert for OD turning, identified as PTGNR 2020 K16, according to ISO. In the tool the cutting edge angle, $\kappa_r = 91^o$, and the clearance angle, $\alpha_n = 0^o$. Two types of inserts were fitted in the tool holder. For both types, the following inserts with different corner radius (r_ε) were used:

1. Conventional geometry inserts:
   - TNMG 160404PF ($r_\varepsilon = 0.4$ mm),
   - TNMG 16 04 08 PF ($r_\varepsilon = 0.8$ mm)
2. Wiper geometry inserts:
   - TNMX 160404WF ($r_\varepsilon = 0.4$ mm),
   - TNMX 16 04 04 WF ($r_\varepsilon = 0.8$ mm).

Both types of inserts were made of GC4215 sintered carbide intended for general turning of steel (P15-P20). According to Sandvik [2], the grade was developed for:

- high–performance steel working, ranging from roughing to finishing,
- processing with cutting fluids (wet machining, WM) or without them (dry machining, DM),
- high temperature cutting applications.

Table 1 Cutting parameters

cutting speed: $v_{c1} = 550$ m/min; $v_{c2} = 475$ m/min; $v_{c3} = 415$ m/min feed: $f_1 = 0.1$ mm/rev; $f_2 = 0.2$ mm/rev; $f_3 = 0.3$ mm/rev depth of cut: $a_p = 1$ mm					
Test number	Parameters	Test number	Parameters	Test number	Parameters
1	$v_{c1}f_1a_p$	4	$v_{c2}f_1a_p$	7	$v_{c3}f_1a_p$
2	$v_{c1}f_2a_p$	5	$v_{c2}f_2a_p$	8	$v_{c3}f_2a_p$
3	$v_{c1}f_3a_p$	6	$v_{c2}f_3a_p$	9	$v_{c3}f_3a_p$

The tests were carried out for the parameters shown in Tab. 1. The parameters were selected on the basis of the manufacturer's specifications [2].

The test stand for measurements of the cutting force at the time of turning consisted of a Haas Sl10 CNC turning lathe, a Kistler 9121 three–component dynamometer, a Kistler 5070 charge amplifier and a Kistler 2855A4 data acquisition card installed in a computer with relevant software [9, 10].

During the processing of the samples the measuring system recorded values of three components of the total cutting force generated by turning: the cutting force, F_c, the back force, F_p, and the feed force, F_f.

The cutting fluid was a conventional BlaserSwisslubeBlasocut fluid supplied to the machining zone at a delivery rate of 5 l/min.

A Hommelwerke T8000 profilometer was used to measure the roughness of 2D surfaces. The averaged values of the three measurements were taken as the final value of roughness for each sample. The *Ra* parameter, which is a common definer of roughness in industrial applications [7], was used in a subsequent analysis of the surface roughness.

3. Test results – measurement of surface roughness,Ra parameter

The results of the measurements of surface roughness *Ra* are presented in Tab. 2.

What can be concluded from the results above is that wiper inserts provide approximately three times lower roughness (*Ra*) of the worked surface, as compared to conventional inserts. It should be noted that at lower machining rates (tests no. 8 and 9) the roughness obtained when turning the material with a wiper insert is, in some cases, as much as five times lower than the reference value. This principle is equally valid for both wet and dry machining.

When comparing the values of roughness obtained for inserts with conventional geometry and the same corner radius r_ε, no significant effect regarding the applied method of cooling and lubricating was observed on the value of *Ra*. In extreme cases the difference was about 4%. However, it should be pointed out that, in the same conditions, the value of *Ra*for the inserts with a corner radius of 0.4 mm was between 62 and 163% greater than for the inserts with $r_\varepsilon = 0.8$ mm.

When comparing the values of roughness obtained for wiper inserts, it was ob-

Table 2 Surface roughness parameter - *Ra*

Test number	Ra [μm]							
	WM				DM			
	TNMG 0,4	TNMX 0,4	TNMG 0,8	TNMX 0,8	TNMG 0,4	TNMX 0,4	TNMG 0,8	TNMX 0,8
1	0,92	0,21	0,50	0,24	0,92	0,34	0,49	0,45
2	2,95	0,45	1,20	0,30	3,01	0,47	1,24	0,36
3	6,89	1,32	2,64	0,67	7,07	1,31	2,69	0,56
4	0,98	0,26	0,56	0,21	0,94	0,44	0,58	0,36
5	2,88	0,48	1,20	0,36	2,98	0,62	1,25	0,34
6	7,12	1,36	2,70	0,63	6,82	1,21	2,62	0,52
7	1,01	0,29	0,53	0,22	0,98	0,38	0,47	0,33
8	3,12	0,50	1,21	0,37	3,03	0,63	1,25	0,38
9	6,91	1,62	2,92	0,59	7,08	1,54	2,87	0,56

served that the values of *Ra*for the inserts with a corner radius of 0.8 mm were greater than for the corresponding inserts with $r_\varepsilon = 0.4$ mm. In some cases, the difference reached 70 to 90%, regardless of the method of application of the cutting fluid. The only exceptions are tests no. 3, 6 and 9, where the feed rate (f_3) was the highest and the *Ra* value was greater in the case of inserts with $r_\varepsilon = 0.4$ mm. Nevertheless, the differences were small, reaching up to 21%.

Changing the cutting speed, v_c, at a constant value of feed, f, did not bring about any significant changes in the value of *Ra* in all test conditions, regardless of the type of insert used.

On the other hand, increasing the feed at a constant cutting speed resulted in a considerable increase in the roughness parameter in all test conditions, regardless of the type of insert. During wet machining, the differences of *Ra*value between subsequent tests reached 290%. The only exception was the wiper insert with $r_\varepsilon =$ 0.8 mm, in which case the differences did not exceed 125%. During dry machining, the differences of *Ra* between subsequent tests were smaller and did not exceed 220%. As an exception to this, in the case of a wiper insert with a corner radius of 0.8 mm the differences did not exceed 60%.

4. Test results – forces generating during turning

Figure 2 shows a sample graph with the components of the total cutting force, F, during turning. The pattern can be divided into the following phases:

1. Increase in force at the moment of penetration,
2. Stabilisation (their mean value remains relatively constant) while turning solid material, and
3. Drop in the level of force when the feed is stopped and the tool withdrawn.

It should be noted that, besides the relatively constant F_s component, there is always a greater or smaller random variable component (noise) F_d. This results from the discontinuous nature of deformations in the shearing zone and chipping. Its amplitude may reach a few dozen per cent of the constant component [8].

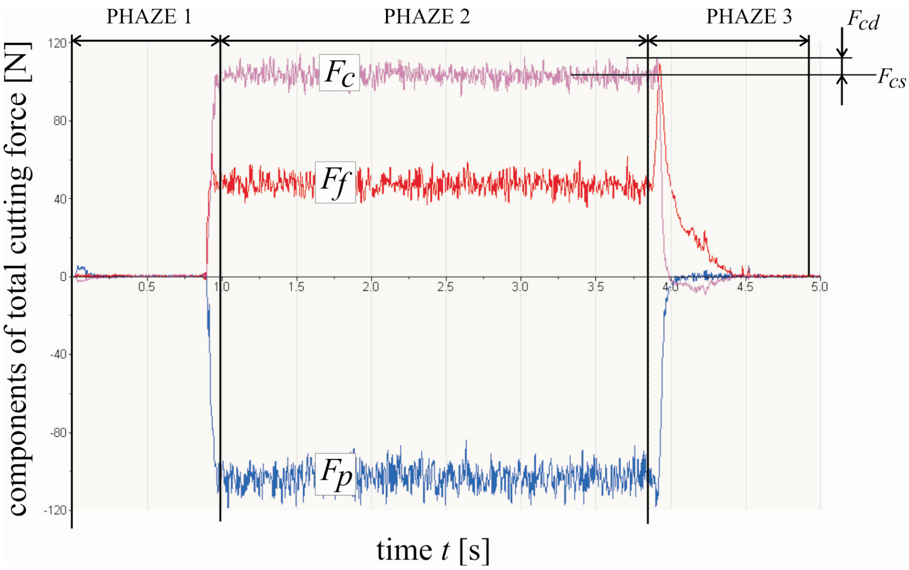

Figure 2 Example signals of component cutting forces

The results of measurements of the cutting forces have been summarised in Tab. 3.

On the basis of the test results it can be concluded that increasing the feed f in constant processing conditions and r_ε results in an increase of the total cutting force and its components regardless of the method of application of cutting fluid. The courses of components F_p and F_c are very similar. A comparable relationship was observed for the feed force F_f and the total force F.

The obtained results indicate that increasing the corner radius (r_ε) during turning by means of wiper inserts causes a significant decrease in the value of F. The difference for the dry machining method (DM) was 35 to 54%, and 35 to 83% for wet machining (WM).

A similar relationship is found in dry turning with inserts of conventional geometry. Here, increasing the corner radius, r_ε, results in a decrease of the total force, F, reaching as much as 69%.

5. Conclusions

On the basis of the results presented above the following conclusions can be drawn:

- The use of wiper inserts produces a considerable reduction of roughness of

Table 3 Components of total cutting force during turning

	Type of insert	Cutting force [N]	Test number								
			1	2	3	4	5	6	7	8	9
Wet Machining	TNMG 0,4	F_p	86	120	170	87	120	176	86	121	173
		F_f	179	209	261	182	212	274	182	216	282
		F_c	175	331	547	197	342	506	229	326	562
		F	**265**	**409**	**630**	**282**	**421**	**602**	**305**	**410**	**653**
	TNMG 0,8	F_p	109	141	170	109	141	172	108	144	176
		F_f	107	127	143	109	128	147	111	132	149
		F_c	129	202	298	208	259	328	230	281	351
		F	**200**	**278**	**372**	**260**	**322**	**399**	**277**	**343**	**420**
	TNMX 0,4	F_p	90	141	200	91	144	205	91	146	209
		F_f	259	333	411	267	343	423	271	351	437
		F_c	361	612	843	381	563	863	367	575	874
		F	**454**	**712**	**959**	**474**	**675**	**983**	**465**	**690**	**999**
	TNMX 0,8	F_p	117	155	199	119	157	203	120	158	205
		F_f	162	181	215	164	185	220	168	189	225
		F_c	152	349	460	284	353	470	193	304	483
		F	**252**	**423**	**546**	**350**	**429**	**558**	**283**	**391**	**572**
Dry Machining	TNMG 0,4	F_p	79	115	157	81	117	160	81	116	165
		F_f	153	185	235	157	189	237	159	194	247
		F_c	172	298	500	236	397	520	302	368	527
		F	**244**	**369**	**575**	**295**	**455**	**594**	**351**	**432**	**605**
	TNMG 0,8	F_p	112	152	190	114	154	192	115	156	196
		F_f	166	188	215	173	193	219	176	199	225
		F_c	182	367	513	256	346	491	290	369	491
		F	**271**	**440**	**588**	**329**	**425**	**571**	**358**	**448**	**575**
	TNMX 0,4	F_p	84	124	163	85,3	125	166	86,0	126	168
		F_f	174	204	236	178	209	243	181	212	249
		F_c	137	361	490	260	345	474	307	374	504
		F	**237**	**433**	**568**	**326**	**423**	**558**	**367**	**448**	**587**
	TNMX 0,8	F_p	104	136	174	106	139	176	106	139	179
		F_f	108	127	152	109	129	155	111	131	157
		F_c	90	180	287	185	236	313	210	258	329
		F	**175**	**259**	**368**	**240**	**303**	**392**	**261**	**322**	**406**

the surface (at least threefold in the considered conditions) as compared to inserts with a conventional corner geometry.

- Increasing the corner radius (r_ε) during turning with wiper inserts results in a substantial increase in the roughness parameter, *Ra*, (up to 70 - 90%). This correlation applies to both methods of application of cutting fluids.
- Changing the cutting speed, v_c, at a constant feed, f, does not result in any significant changes in the *Ra*value in all conditions considered, regardless of the type of cutting tool used.
- Increasing the feed rate, f, at a constant cutting speed, v_c, results in a substantial increase of the surface roughness parameter, *Ra*, (by as much as 290%) in all conditions, regardless of the type of cutting tool used.
- Increasing the corner radius, r_ε, during turning by means of wiper inserts results in a considerable decrease of the force, F. The difference ranges from 35 to 54% in the case of dry machining, and 35 to 83% in wet machining.
- Increasing the feed rate, f, in constant conditions and corner radius, r_ε, results in an increase of the total cutting force and its components, regardless of the method of application of cutting fluids and for each type of insert used.

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