OPTIMIZATION OF CUTTING TOOL GEOMETRICAL PARAMETERS USING TAGUCHI METHOD

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Abstract: *The study developed in this paper presents the finite element analysis of the influence of cutting tool geometrical parameters: nose radius, rake angle and clearance angle – on the some evaluation indicators of the machining process, namely: cutting forces, temperatures and thermal deformations of the tool. To optimize the geometric parameters of the cutting tool was used statistical method of signal – noise ratio.*
Key words: *cutting tool optimization, Taguchi method, finite element analysis, machining process.*

1. INTRODUCTION

As is known, the performance of the cutting process is influenced by the machining parameters and the geometrical parameters of the cutting tool. Due to the actual requirements of the cutting and cutting tools domain, tool manufacturers must continually optimize the geometric parameters of the cutting tool.
In order to avoid high consumption of materials and tools as well as time and costs they involve, the researchers of the cutting tool domain propose new solutions to optimize machining process.
Zouhar and Piska presents the research results which refer of the cutting process simulation using cutting tools with different geometries both, for the rake angle and tool nose radius (Zouhar & Piska, 2008). They show that the cutting forces increase is significantly influenced by increasing the rake angle of the tool, and on the other hand, increasing the nose radius of the tool leads to reduced forces.
The optimization of cutting process parameters using the ANT colony algorithm, in order to achieve a minimum surface roughness, is the object of study for researchers Pansare and Kavade. They want to emphasize that the proposed method is efficiency due to experimental results (Pansare & Kavade, 2012).
Effect of tool edge geometry and cutting conditions on the chip morphology in orthogonal hard turning of 100Cr6 steel is studied by Kountanya and et al.. They show that the edge radius does not influence the geometrical parameters of the chip, cutting forces decrease with cutting speed increasing and the chip formation frequency increases linearly with cutting speed, while a negative rake angle increases the chip pitch (Kountanya et al., 2009).
The impact of the cutting speed, feed and depth of cut on the quality of the machined surface have analysed by Mahapatra and et al.. They propose a prediction model for surface roughness and optimization of cutting parameters using genetic algorithms (Mahapatra et al., 2006).
Kurt and Şeker investigates the effect of chamfer angle of polycrystalline cubic boron nitride cutting tool on the cutting forces and the tool stresses in finishing hard turning of AISI 52100 steel. The results obtained by them, show that an angle of 20˚ has a major influence on the cutting forces and von Mises stresses (Kurt & Şeker, 2005).
Aruna and Dhanalksmi propose the optimization of cutting parameters in turning of Inconel 718 with response surface method. Thus, the parameters obtained by optimization are validated by experimental tests (Aruna & Dhanalksmi, 2012).
The major objective of this paper is to determine the optimum geometrical parameters of the cutting tool using both, finite element analysis and Taguchi method.

2. CASE STUDY

The proposed study, analyzes the influence of the nose radius, rake angle and clearance angle on the cutting forces F_y and F_z, cutting zone temperature and thermal deformation of the tool.
The study was realized in according to the following steps:
(1) design plan of experiments;
(2) finite element simulation of the cutting process in according with the plan of experiment;
(3) the calculation of signal to noise ratio;
(4) identifying the optimal test.

(1) *Design plan of experiments*
At this stage, an orthogonal experimental plan was developed, in which were varied on three levels, three geometric parameters of the tool: nose radius, rake angle and clearance angle. Three values were considered for the nose radius: 0.4mm, 0.8mm and 1.2mm. For the rake angle were selected following values: 6, 7, 8 and for the clearance angle, 8, 10 and 12.
In table 1 is shown the plan of experiments with the three levels of variation and the three factors of influence.

(2) *Finite element simulation of the cutting process in according with the plan of experiment*
For the finite element simulation of the cutting process, we used Deform 2D software. For the tests simulation, machining parameters were kept constant, so that the cutting speed was set to 280m/min, the feed rate to 0.23mm/rev and depth of cut to 1.5mm. In order to study the influence of geometrical parameters on the cutting forces, temperatures and thermal deformations of the tool, the values of the nose radius, rake angle and clearance angle, were considered variables. Regarding the choice of materials for tool and work piece, tungsten carbide was chosen for the tool and AISI 1045 carbon steel for the work piece.
The results obtained by finite element simulation, are presented in table 2. Studied values, represents the average values of forces, temperatures and thermal deformations of the tool.

Table 1. Orthogonal plan of experiments.

Test	Input parameters		
	r_β [mm]	γ [°]	α [°]
1	0.4	6	8
2	0.4	7	10
3	0.4	8	12
4	0.8	6	10
5	0.8	7	12
6	0.8	8	8
7	1.2	6	12
8	1.2	7	8
9	1.2	8	10

(3) *The calculation signal to noise ratio*
The method of statistical analysis signal to noise ratio, developed by Taguchi, has been applied in this paper in order to identify the optimum combination of tool geometric parameters, but and the output parameters on which they action.
This ratio was calculated using the formula (Julean, 2003):

$$\frac{S}{N} = -10 * \log(s^2 + \bar{y}^2)\ [\text{dB}] \quad (1)$$

where, s is the standard deviation of the measured values;
y – arithmetic mean of the measured values.
In table 2 are summarized the results for the signal to noise ratio.

(4) *Identifying the optimal test*
The optimum ratio is identified by the maximum calculated value. According to table 2, the maximum value of S/N ratio was obtained for the test 3. So, we can say that the test 3 is the optimum combination of the nose radius, rake angle and clearance angle for this study. These values can be seen in table 3.

3. RESULTS AND DISCUSSION

Next, we will present the influences of geometric parameters of the cutting tool on the forces, temperatures and thermal deformations. To understand better these influences, we calculated the average values of cutting forces, temperatures and thermal deformations for each value of radius, rake angle and clearance angle, separately. These values are presented in table 4.

(a) *Influence of the nose radius*
The values of the F_z forces increases significantly with the nose radius increasing (table 4). It can be seen that increasing the nose radius, leads to a higher F_z force with approximately 360-400N. If we analyse the values of F_y forces, can be observed that there is an increase of about 140N with nose radius increasing.
Regarding the influence of nose radius on the temperature, it can be seen that the highest temperature values were obtained for a nose radius of 0.8mm. Also, it can be observed that the lower temperature has been obtained for a nose radius of 0.4mm (table 4).

Table 2. Output parameters and S/N ratio values.

Test	Input parameters			Output parameters				S/N [dB]
	r_β [mm]	γ [˚]	α [˚]	F_y [N]	F_z [N]	T [˚C]	Tool deformation [mm]	
1	0.4	6	8	519.597	666.481	493.244	0.002464	-54.1564
2	0.4	7	10	560.541	650.820	506.55	0.002765	-54.3131
3	0.4	8	12	519.520	659.054	460.140	0.002942	-53.9686
4	0.8	6	10	678.592	1042.683	708.66	0.003680	-57.484
5	0.8	7	12	667.797	1051.871	894.76	0.003356	-58.0748
6	0.8	8	8	677.331	1053.769	720.580	0.003824	-57.5657
7	1.2	6	12	822.55	1408.071	689.75	0.004295	-57.8795
8	1.2	7	8	814.806	1423.252	701.773	0.004008	-59.4479
9	1.2	8	10	799.120	1402.868	699.350	0.003645	-59.3274

Table 3. The optimal parameters of cutting tool geometry.

r_β [mm]	γ [˚]	α [˚]	F_y [N]	F_z [N]	T [˚C]	Tool deformation [mm]	S/N [dB]
0.4	8	12	519.520	659.054	460.140	0.002942	-53.9686

Table 4. Means value of the output parameters.

Geometric parameters of the tool		F_y [N]	F_z [N]	T [˚C]	Tool deformation [mm]
r_β [mm]	0.4	533.21	658.785	486.644	0.0027236
	0.8	674.573	1049.441	774.66	0.00362
	1.2	812.158	1411.397	696.95	0.0039826
γ [˚]	6	673.579	1039.07	630.551	0.0033763
	7	681.048	1041.981	701.027	0.0034796
	8	665.32	1038.56	626.69	0.0034703
α [˚]	8	670.578	1047.834	638.532	0.003432
	10	679.417	1032.123	469.336	0.0033633
	12	669.955	1039.665	681.55	0.003531

Another effect that it has the nose radius refers to the thermal deformation of the cutting tool. With nose radius increasing, increase the value of the tool thermal deformation. What is important to note, is that for a value of 0.4mm, cutting tool deform on the radius and rake face direction, and for the other two values, the deform take place on the radius and clearance face direction (Fig.1).

(b) *Influence of the rake angle*

If we study the influence of the rake angle on the forces, from Fig.2, it can be seen that these values are kept approximately constant, and the lower force values were obtained for an angle of 8˚.

Regarding to the temperature variation and thermal deformation with the rake angle, the results show that the highest values were recorded for an angle of 7˚ (Figs.3 and 4).

(c) *Influence of the clearance angle*

The forces value can be considered approximately constant, and in the case of temperature there is a reduction with 170˚-200˚ for a rake angle value of 10˚ compared with 8˚ and 12˚ (Figs.5 and 6). From Fig. 7, it can be seen that the thermal deformation of the tool also decreases for a 10˚ rake angle value.

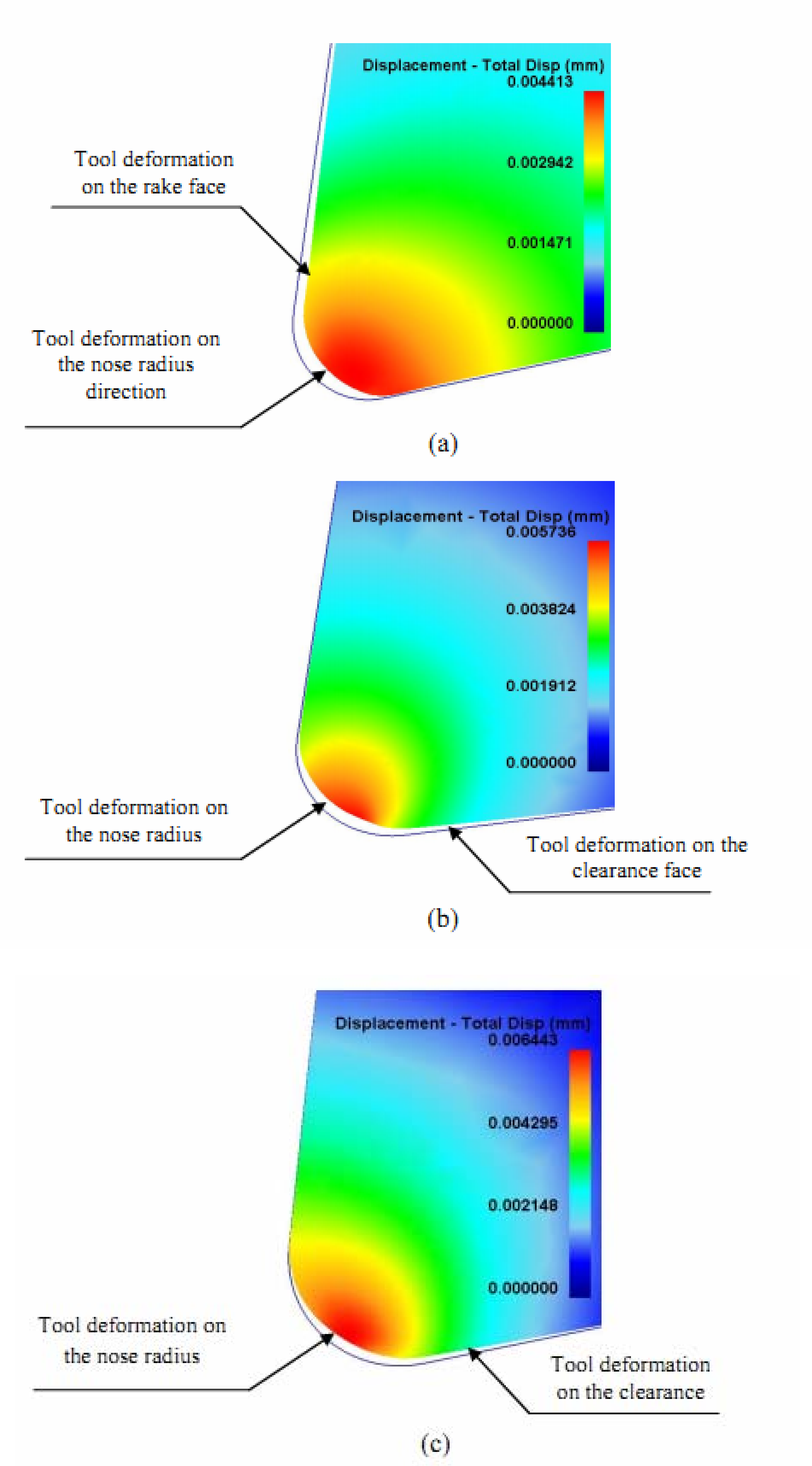

Fig.1. Thermal deformation of the cutting tool: (a) for r_{β}=0.4mm; (b) for r_{β}=0.8mm; (c) for r_{β}=1.2mm.

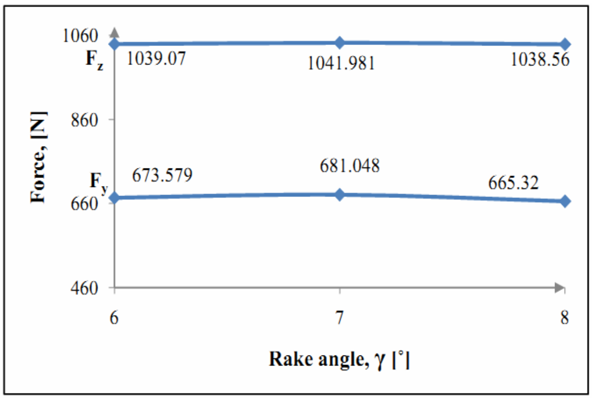

Fig.2. Variation of the cutting forces with rake angle.

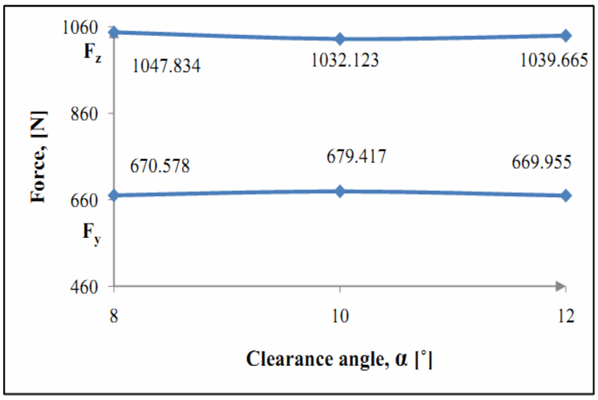

Fig.5. Variation of the cutting forces with clearance angle.

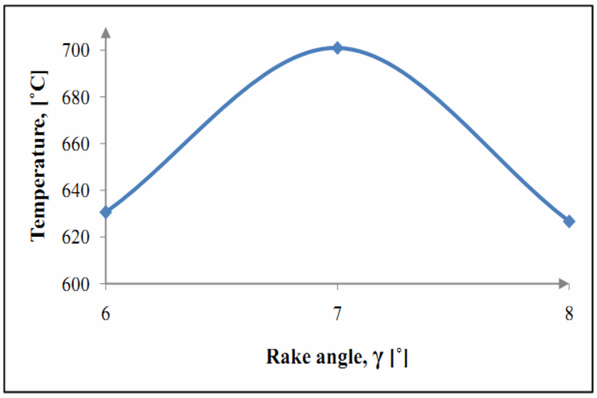

Fig.3 Variation of the temperature with rake angle.

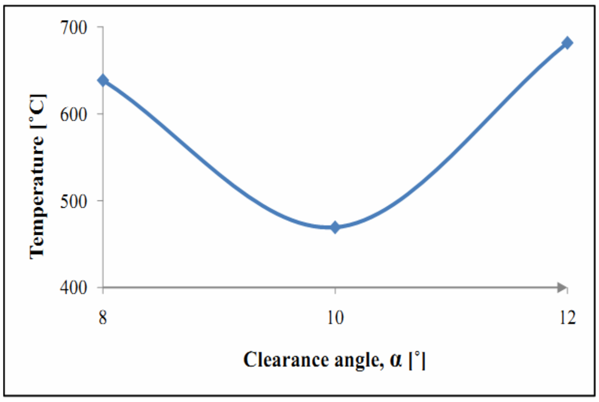

Fig.6. Variation of the temperature with clearance angle.

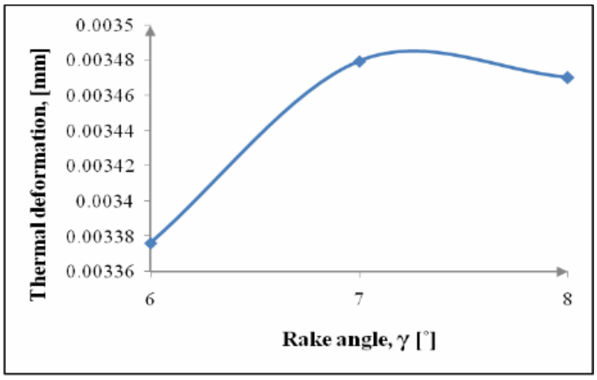

Fig.4. Variation of the thermal deformation with rake angle.

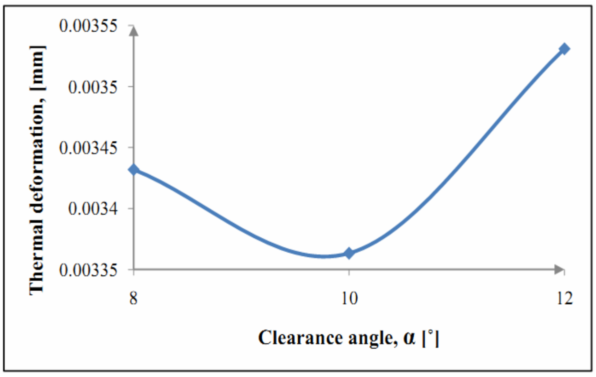

Fig.7. Variation of the thermal deformation with clearance angle.

4. FURTHER RESEARCH

Deform 2D was used to analyze the influence of the nose radius, rake angle and clearance angle on the cutting forces, temperatures and tool deformations.
But in addition to the investigation of these parameters, further research is needed regarding the principal stresses which acting on the cutting tool, because they lead to modifies at the geometry of the tool and therefore its wear.

On the other hand, experimental tests are needed to validate theoretical research, presented in this paper.

5. CONCLUSIONS

In this paper, the influence of tool geometric parameters on the cutting forces, temperatures and thermal deformation of the tool was investigated. The study involves both, finite element analysis and optimization of cutting tool geometric parameters by Taguchi method.

Thus, in agreement with the results obtained it can be concluding that:

- force values increase with nose radius increase;
- the lowest forces value were recorded for a nose radius of 0.4mm;
- the lowest temperature value was also obtained for a nose radius of 0.4mm;
- with nose radius increasing, the thermal deformation increases;
- the rake angle and clearance angle value has a small influence on the cutting forces;
- test 3 represents the optimal test for the tool geometric parameters (table 3).

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