Methodology Modeling of Parts with Replaceable Hard Alloy Plates Types in the SolidWorks System

Mohammad Ayaz Ahmad[1*], Svitlana Sotnik[2], Tetiana Sinelnikova[3], Vyacheslav Lyashenko[3]

[1]Department of Physics, Faculty of Science, P.O. Box 741, University of Tabuk, 71491, Saudi Arabia
[2]Department of Computer-Integrated Technologies, Automation and Mechatronics, Kharkiv National University of Radio Electronics, Kharkiv, Ukraine
[3]Department of Informatics, Kharkiv National University of Radio Electronics, Kharkiv, Ukraine

Abstract: To model the milling process, you need an accurate model of the cutting tool. The article presents a methodology developed for designing a part with replaceable "end milling cutter" plates in a three-dimensional configuration. The model of a "face milling cutter" type with carbide inserts includes a large number of variables, such as diameter, number of teeth, their clearance angles, and the like. Therefore, the geometry of such a cutting tool is chosen on the basis of similar details studies. The proposed model was developed using the CAD system of SolidWorks. The cutting insert deformation of the milling cutter in the SolidWorks Simulation module is analyzed, as a result of the calculated cutting force acting on it, it is determined that the cutting inserts meet the accuracy requirements for surface treatment of grade 2-4.
Keywords: Modeling, SolidWorks, CAD, end milling machine, milling machine, interchangeable plate type.

INTRODUCTION

In the world market there is a large number of firms engaged in the cutting tools production. Leaders in this area are: concern Sandvik (in it, besides the company of the same name, includes Walter, SECO, Titex, Prototyp, Dormer and others); Kennametal, ISCAR, Mitsubishi [1].

All the variety of cutting tools can be divided into two large groups: a monolithic tool and a tool with replaceable plates (inserts) [1].

However, in most cases it is advisable to use a tool with replaceable plates. This turns out to be economically more efficient, since there is no need to re-sharpen the instrument. In addition, by replacing the plates, the operator can always be sure of the processing conditions stability, that is, there is no need to adjust the cutting modes or re-attach the tool.

Recently, methods of final flat surfaces processing with finishing end mills have become widespread. This is because milling, in comparison with grinding, is characterized by higher productivity and dimensional stability of the tool, which provides fewer defects in the surface layer [2]. As a rule, responsible parts of machines, precision equipment, metal-cutting machines are subject to such processing. Consequently, the operability of such parts requires the necessary contact stiffness and wear resistance of the joints, so they must have minimal deviations from flatness and the necessary surface roughness.

When designing end mills, the features of finishing machining - cutting with small shear thicknesses are often not taken into account, the complete participation questions of cutting elements in cutting and the renewal of the mills cutting ability are unsatisfactorily solved. This leads to increased dynamics of the milling process and does not allow the unique cutting properties to be fully realized. However, as practice has shown, taking measures to eliminate or reduce the influence of unfavorable factors on the durability and productivity of the milling process, it is possible to achieve in most designs of mills a wide application of new cutting materials grades and mainly hard alloys [3].

Modern production is more or less automated, the use of computer-aided design (CAD) systems such as CATIA, T-Flex, Unigraphics, Auto CAD, SolidWorks is especially popular. CAD allows you to develop 3D models of various tools and simulate various loads on them in order to determine the design

features and material of the part immediately before it is manufactured.

MATERIALS AND METHODS
Related work
There has been an extensive research into the prediction or cutting forces in end milling, most of which have produced very good results. Majority of these are analytical based, involving quite a number of calibration experiments used to obtain cutting force coefficients (mechanistic approach), or solving of small oblique segments along the tool's cutting edge (mechanics approach). Other studies are based on computational simulations mainly using finite element (1*12) techniques [4].

Analytical modeling and experimental validation of micro end-milling cutting forces considering edge radius and material strengthening effects are presented in [5]. Authors presents a novel micro end-milling cutting forces prediction methodology including the edge radius, material strengthening, varying sliding friction coefficient and run-out together. A new iterative algorithm is proposed to evaluate the effective rake angle, shear angle and friction angle, which takes into account the effects of edge radius as well as varying sliding friction coefficient. A modified Johnson–Cook constitutive model is introduced to estimate the shear flow stress. The model considers not only the strain-hardening, strain-rate and temperature but also the material strengthening.

In the [6] modeling of cutter displacements during ball end milling of inclined surfaces. This work concentrates on the modeling of cutter's displacements during ball end milling with various surface inclinations. The cutter's displacements (vibrations) model including: tool's geometry, cutting conditions, surface inclination angle, run out and tool's deflections (induced by the cutting forces) was proposed. In work experiments were carried out with the application of laser displacement sensor and force dynamometer. The research revealed that cutter's displacements are strongly affected by the cutter's run out and surface inclination. The observation is also confirmed by the developed model.

Modeling of cutting forces in end milling based on oblique cutting analysis is given in [7]. The proposed model has been verified with various cutting tests using regular end mill and variable helix end mill. The predicted and measured cutting forces are compared to illustrate the viability of the proposed cutting force model in end milling.

Optimization of AISI 1045 end milling using robust parameter design was described in [8]. This study aims to optimize the end milling of AISI 1045 steel, using carbide inserts coated with titanium nitride (TIN). The process parameters analyzed include cutting speed, feed per tooth, axial depth of cut, and radial depth.

3D Parametric Modeling of Milling Cutter Geometry from Analytical Analysis are presented in [9]. Authors describe the methodology developed to design flat and ball end mills in three-dimensional configuration. The geometry of these cutters is issued from an analytic study based on oblique cutting theory. The described model is performed by using parametric CAD software. Hence, it involves a big number of variables as the diameter, the helix, the rake and the clearance angles and the teeth number.

Review details of the type "end milling cutter"
In order to realize the modeling of a "end milling cutter" type with carbide plastics it is necessary to consider and analyze the entire variety of cutting tools. The most promising are cutters with replaceable plates.

On the basis of technology distinguish cutters for processing [1]:
- Planes;
- Grooves and splines;
- Shaped surfaces;
- Cutting material, etc.

Consider these types using the example of mills produced by Sandvik.

For the treatment of planes and ledges, Sandvik produces a variety of mills with different plate shapes and angles in plan. The CoroMill 245 families (Figure 1, a) and 290 (Figure 1, b) - the angle in the plan of 45 ° and 90 °, are designed to remove a large volume of material along the plane for chamfering. Provides high surface purity [10, 11].

CoroMill 390 (Figure 1, c) is a more versatile cutter whose plates have a spiral cutting edge, which contributes to smoother cutting. Designed for working planes, ledges, screw interpolation [11].
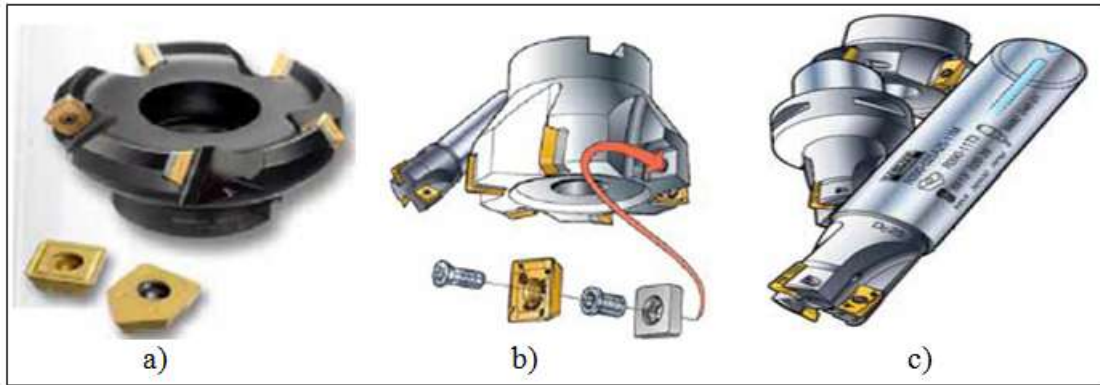
Fig-1: Cutters of the Coro Mill families

When choosing a milling cutter, they are guided first of all by such parameters:

- Diameter and length of the working part;
- Profile shape of the working part;
- Material of the working part;
- Number and pitch of teeth (cutting faces);
- The shape and size of the fastening part.

The pitch of the cutter teeth can be large, normal and fine. Mills with different tooth pitch are designed for various processing conditions in terms of its stability, energy consumption and the presence of a propensity to vibrations. A reduced number of plates is the standard solution for productive processing with insufficient machine power or low rigidity of the machine. The machine is a tool-tool-part. Mills with a normal pitch are universal for most operations [12].

RESULTS AND DISCUSSION
3D model creation of a "end milling cutter" type

For modeling, the SolidWorks editor has been selected, since it allows you to arbitrarily change parts directly from the assembly. The connection between parts and assembly guarantees their synchronous updating when changing any parameters. Therefore, assembly drawings can be created at any design stage.

To quickly create a number of similar objects, special commands "line array" and "circular array" can be used. In a circular array, the user specifies the element's sample, the number of elements in the array, and the characteristic dimensions. Likewise, a linear array is created. Conveniently, the similar elements created in this way do not contain any interconnections by default, that is, changing one of them does not automatically change the others [13].

Let's consider in more detail the process of creating a milling cutter body. To create a new three-dimensional model, select the "Model" item in the model creation window, specify a name and specify the folder to save.

The first step in creating a model is to create a sketch. To do this, the "Sketch" tab is selected on the control panel. In the appeared sketch creation window, you must specify the sketch parameters: select the plane or face on which the sketch will be created. First, using a straight line, draw a contour of the cutter body. Then use the "Rotated boss" element to create a body of rotation around the center line. The result of these actions is shown in Figure 2, a.

In SolidWorks, you can create sketches on any plane. To create a cut in the cutter body, you again need to select the front, plane and create a cutout sketch on it. Then select the tool "Rotated cutout", resulting in a cutout in the cutter body, as shown in Figure 2, b.
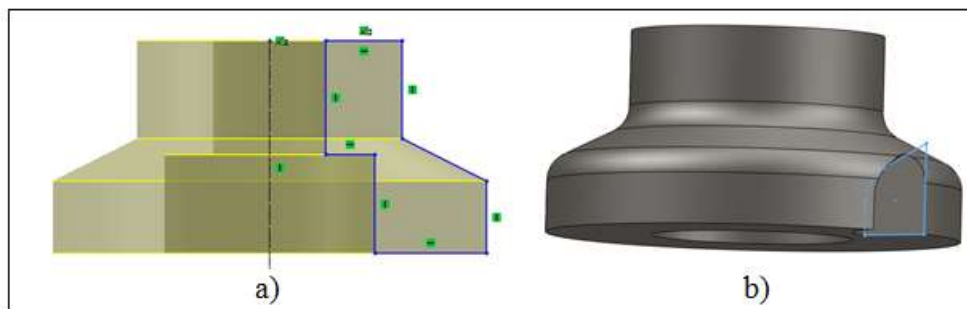

Fig-2: The obtained body of rotation

In the course of the work, the optimal number of teeth for the cutter was determined. 10. In order to create 10 notches symmetrically arranged along the circumference, the command "Circular array" was used

(Figure 3, a). To make a cutout for fastening the cutter on the mandrel with an end key, a sketch is created on the top plane. After that the tool "Extruded cutout" is again selected, and the rounding tool is applied to the lower edges of the cutout (Figure 3, b).

A 3D model of the cutting insert has also been created. To do this, select the sketch and draw a rectangle, then use the "Pull out" tool to draw the element to the desired length. After adding a fillet with a radius of 0.8 mm (Figure-3, c).

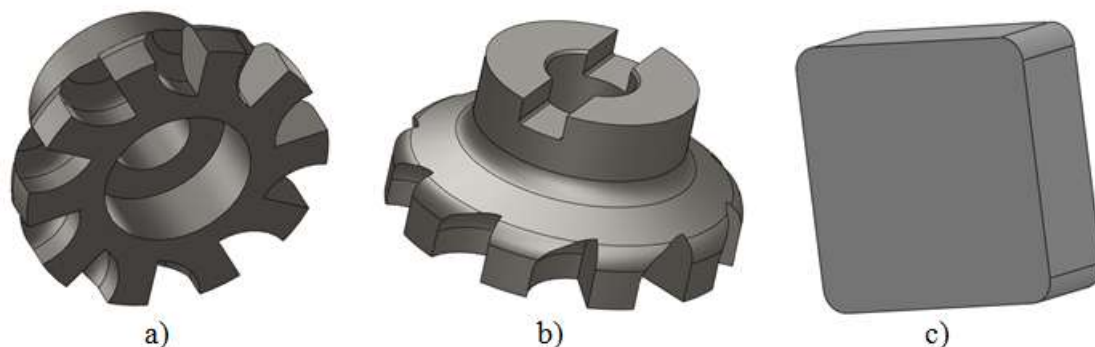The final result of the assembly is shown in Figure 4.
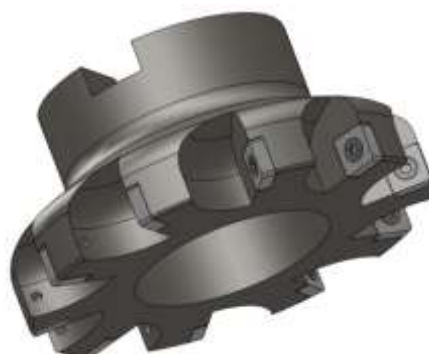

Fig-3: Simulation of the mill

Fig-4: The result of the assembly

Analysis of the cutting insert deformation

To model the cutting insert deformation, the SolidWorks Simulation module was selected by the cutting force [14]. This module allows you to calculate the design for strength, stability, mimic the fall conditions, perform thermal calculations, optimize the model parameters and much more.

To begin with, you need to select the "New Study" item in the "Simulation" tab. After this, you need to specify the specific conditions under which the test will be carried out:
- Material of parts;
- Ways of fastening;
- Forces and directions of their application;
- Types of connections;
- Mesh density.

The material for the part is T5K10. In the standard library of SolidWorks materials there is no information on the T5K10 alloy, so you need to create a new material. Materials in the library can not be edited directly, so you must first copy any of the materials, and then replace the characteristics with the required ones (Figure 5).
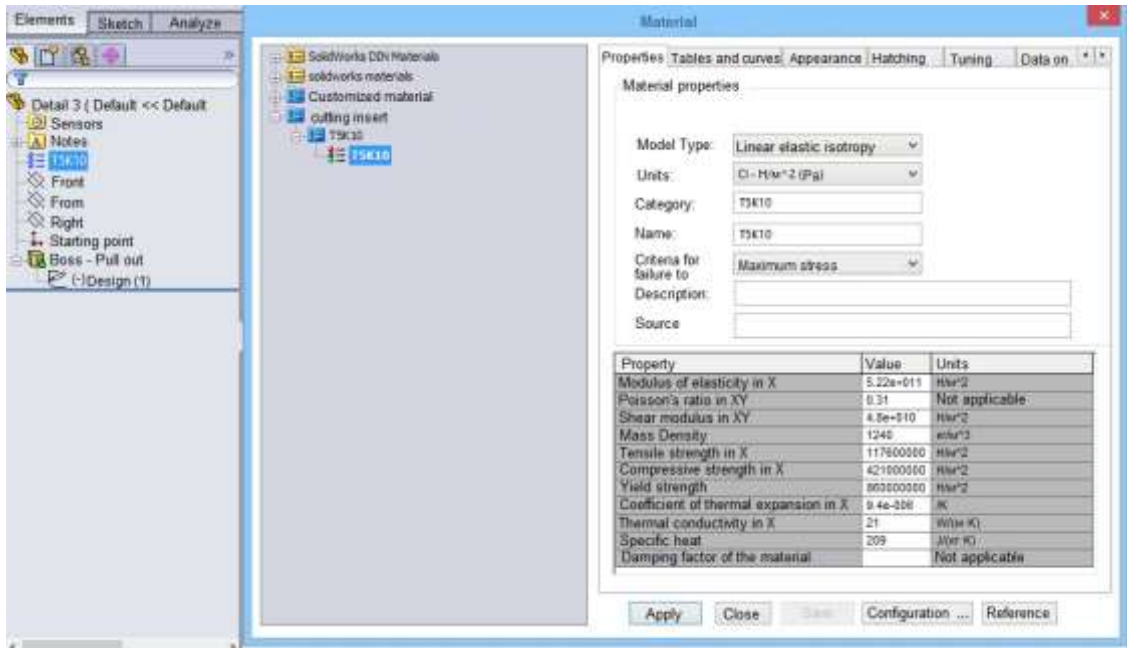
Fig-5: Setting the parameters of the alloy T5K10

For the body of the mill, material was selected from the standard SolidWorks library - steel 45. After selecting the material, a force of 3726 N and a plane on the cutting insert to which it was applied were given. The connection was also made with the screw for the cutting insert and a fixed mounting for the housing. The milling cutter screws are not modeled in this case, but only its parameters are set in the connection dialog box.

After that, a grid was created for analysis using the finite element method.

The density of the grid affects the accuracy of the calculation, but a high density grid can negatively affect performance, so the grid was created automatically to achieve the optimum size of the elements. Assembly with all the specified parameters is shown in Figure 6.
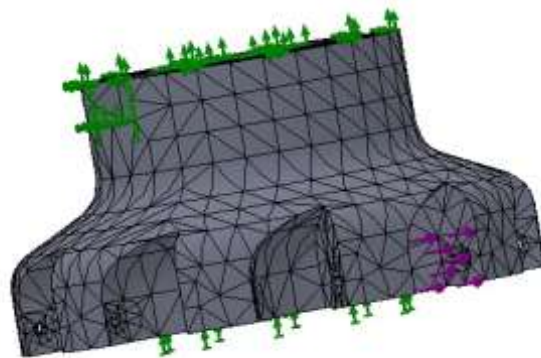

Fig-6: Setting parameters for calculation

After completing all the necessary steps, the "Start" operation is selected. Thus, in the SolidWorks Simulation module, an analysis of the cutting insert

deflection was performed as a result of the calculated cutting force applied to it (Figure 7).
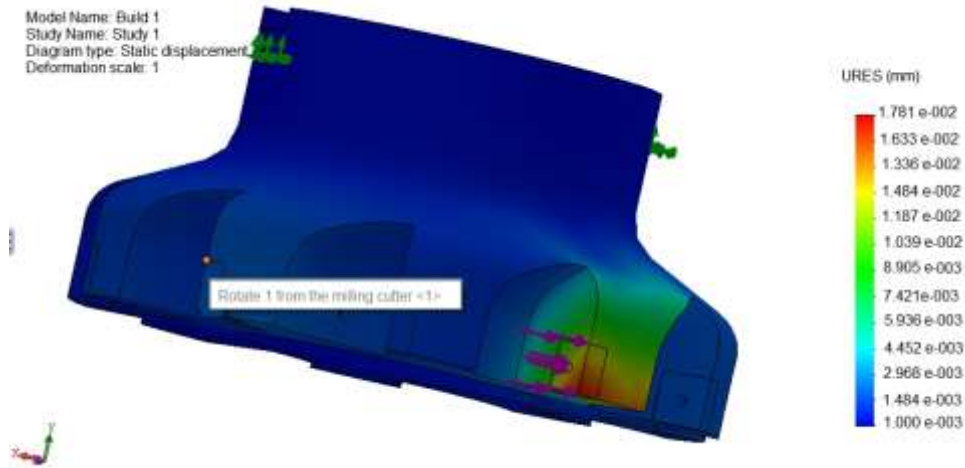
Fig-7: Diagram of the movement distribution

However, in a real situation, the machine operator can change the cutting parameters to achieve the most optimal operating mode. Because of this, the cutting tool can be subjected to additional loads, and consequently, to experience large deformations. To predict the behavior of the cutting tool under loads other than the calculated one, an additional study was conducted in SolidWorks Simulation. With the help of this module, strain values were calculated for forces from 0.4R to 2R. The results of the analysis are presented in Table 1.

On the basis of the obtained data, the graph shown in Figure 8.

Table-1: The values of the cutting insert deflection for different cutting forces

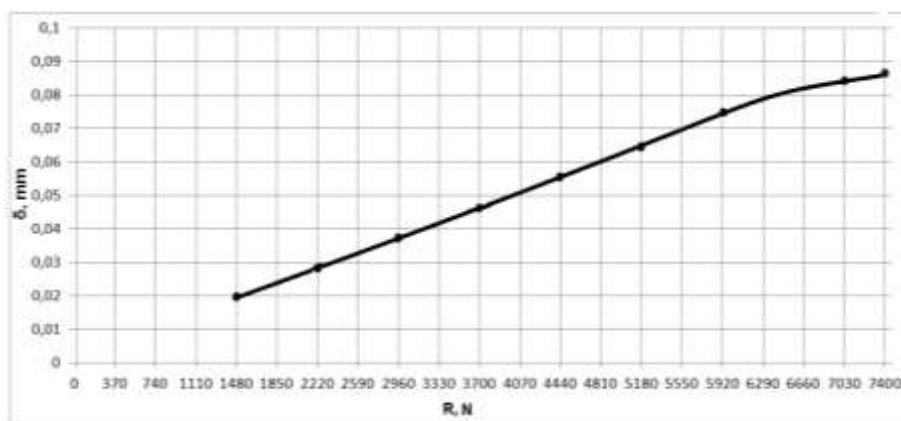| Cutting force R, N	The magnitude of the deflection δ, mm
1490.4	0.01847
2235.6	0.02711
2980.8	0.03822
3726.0	0.04609
4471.2	0.05580
5216.4	0.06747
5961.6	0.07455
6707.8	0.08603
7252.0	0.09397

Fig-8: The amount of cutting insert deflection, depending on the cutting force

From the data obtained, it can be seen that the maximum value of the cutting insert deflection at the design cutting force is 46 μm, which corresponds to the requirements for a clean surface treatment of grade 2-4. It also shows from the results that the deflection of the top plate is directly proportional to the magnitude of the force R. With increasing cutting force, the amount of deflection also increases. Due to this schedule, the operator of the machine can take into account the expected deflection of the plate when the calculated cutting force is exceeded and adjust its actions to obtain the required processing accuracy.

DISCUSSION OF THE RESULTS

Since one of the milling defects causes can be defects "obtained" during their processing, it is suggested to simulate the cutting tool for milling, since it is this processing that is characterized by higher productivity and dimensional stability of the tool. To solve such problems, a 3D model of a cutting tool such as a "face milling cutter" was created.

As a result, the diameter of the mill (160 mm) is determined, the number of teeth (10) is determined, the cutting force (3726 N) is determined. As the material for the cutting insert, the T5K10 alloy is chosen, since it has high operational strength.

Also a finite element analysis of the developed part was made, for which the decision program Direct Sparce was chosen. Due to the analysis of the selected type, it is confirmed that with increasing cutting force, the deflection value also increases.

CONCLUSION

In this work, the "end milling cutter" part is modeled with plates of hard alloy T5K10. Based on the analysis of the cutting insert deformation of the milling cutter in the SolidWorks Simulation module, as a result of the calculated cutting force acting on it, it is determined that the maximum deflection of the cutting insert at the design cutting force is 46 μm, which corresponds to the accuracy requirements for surface treatment of grade 2-4.

In the work the diagram of the displacement mill distribution is given. On the basis of the obtained data, a graph of the deflection amount dependence of the cutting insert on the cutting force is constructed. The obtained data can be further used to optimize the existing technology for processing parts and improve the quality of the part. This will also significantly reduce the time for designing this type of milling cutter.

ACKNOWLEDGMENT

REFERENCES

1. Stephenson, D. A., & Agapiou, J. S. (2016). *Metal cutting theory and practice*. CRC press.
2. Cai, Y., Liu, Z., Shi, Z., Song, Q., & Wan, Y. (2017). Optimum end milling tool path and machining parameters for micro Laval nozzle manufacturing. *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture*, *231*(10), 1703-1712.
3. Dabhi, B. R., & Parmar, K. V. (2015). A review paper on latest trend on face milling tool. *Development*, *2*(1). 59-61.
4. Kumar, M. (2017). Modeling and Simulation of Surface Texture for End-Milling Process: Modeling End-Milling Process. In *Handbook of Research on Manufacturing Process Modeling and Optimization Strategies* (pp. 19-39). IGI Global.
5. Zhou, L., Peng, F. Y., Yan, R., Yao, P. F., Yang, C. C., & Li, B. (2015). Analytical modeling and experimental validation of micro end-milling cutting forces considering edge radius and material strengthening effects. *International Journal of Machine Tools and Manufacture*, *97*, 29-41.
6. Wojciechowski, S., Chwalczuk, T., Twardowski, P., & Krolczyk, G. M. (2015). Modeling of cutter displacements during ball end milling of inclined surfaces. *Archives of Civil and Mechanical Engineering*, *15*(4), 798-805.
7. Lin, B., Wang, L., Guo, Y., & Yao, J. (2016). Modeling of cutting forces in end milling based on oblique cutting analysis. *The International Journal of Advanced Manufacturing Technology*, *84*(1-4), 727-736.
8. Brito, T. G., Paiva, A. P., Paula, T. I., Dalosto, D. N., Ferreira, J. R., & Balestrassi, P. P. (2016). Optimization of AISI 1045 end milling using robust parameter design. *The International Journal of Advanced Manufacturing Technology*, *84*(5-8), 1185-1199.
9. Nasri, A., Slaimi, J., & Sai, W. B. (2016). 3D Parametric Modelling of Milling Cutter Geometry from Analytical Analysis. *Science, Technology and Society*, *4*(2), 35-40.
10. Zhilevski, M., & Mikhov, M. (2015). Study of Electric Drives for Rotary Table of Milling Machines. *Journal of Multidisciplinary Engineering Science and Technology*, *2*(40), 607-611.
11. Zarkti, H., El Mesbahi, A., Rechia, A., & Jaider, O. (2015, December). Towards an Automatic-optimized tool selection for milling process, based on data from Sandvik Coromant. In *Xeme Conference Internationale: Conception et Production Intégrées*.
12. Lai, C. H., & Yang, H. C. (2016). Theoretical investigation of a planar rack cutter with variable diametral pitch. *Arabian Journal for Science and Engineering*, *41*(5), 1585-1594.
13. Howard, E., & Musto, J. C. (2005). *Introduction to solid modeling using Solidworks*. McGraw-Hill.
14. Onwubolu, G. C. (2017). *Introduction to SolidWorks: A Comprehensive Guide with Applications in 3D Printing*. CRC Press.
15. Lyashenko, V., Ahmad, M. A., Sotnik, S., Deineko, Zh., & Khan, A. (2018). Defects of Communication Pipes from Plastic in Modern Civil Engineering. *International Journal of Mechanical and Production Engineering Research and Development, 8*(1), 253-262.

16. Sotnik, S., Matarneh, R., & Lyashenko, V. (2017). System Model Tooling For Injection Molding. *International Journal of Mechanical Engineering and Technology, 8*(9), 378–390.

17. Lyashenko, V, Ahmad, M. A., Kobylin, O., & Khan, A. (2017). Study of Composite Materials for the Engineering using Wavelet Analysis and Image Processing Technology. *International Journal of Mechanical and Production Engineering Research and Development, 7*(6), 445-452.

18. Khan, A., Joshi, S., Ahmad, M.A., & Lyashenko, V. (2015). SomeEffect of ChemicalTreatment by Ferric Nitrate Salts on the Structure and Morphology of Coir Fibre Composites. *Advances in Materials Physics and Chemistry, 5*(01), 39-45.

19. Ahmad, M. A., Lyashenko, V. V., Lyubchenko, V. A., Khan, A., & Kobylin, O. A. (2016). The Methodology of Image Processing in the Study of the Properties of Fiber as a Reinforcing Agent in Polymer Compositions. *International Journal of Advanced Research in Computer Science*, *7*(1), 15-18.

20. Lyashenko, V. V., Ahmad, M. A., Lyubchenko, V. A., Khan, A., & Kobylin, O. A. (2016). Image Processing a New Era in the Study of Natural Polymer Composites. *Asian Academic Research Journal of Multidisciplinary*? *3*(3), 288-300.

21. Putyatin, Y. P., Ahmad, M. A., Lyashenko, V. V., & Khan, A. (2016). The Pre-Processing of Images Technique for the Material Samples in the Study of Natural Polymer Composites. *American Journal of Engineering Research*, *5*(8), 221-226.

22. Lyashenko, V., Kobylin, O., & Ahmad, M. A. (2014). General Methodology for Implementation of Image Normalization Procedure Using its Wavelet Transform. *International Journal of Science and Research (IJSR)*, *3*(11), 2870-2877.