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Simulation Analysis of Uncoated Tungsten Carbide in Turning Process for AISI 1045 Carbon Steel

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Abstract: Turning operation is a very common machining process in industry and experimental trial and observation are widely used for the optimization process of setup parameters, which are expensive and time consuming. The objectives of this study are to simulate two dimensional cutting tool wear of uncoated tungsten carbide (WC) in turning process for AISI 1045 carbon steel using finite element method and to determine the effect of stress, strain, and temperature to the changes of cutting tool edge radius. DEFORM-2D FEM software is employed to assist the simulation process where rounded edge cutting tool is used and assumed as rigid body and the work piece is prescribed as thermo-plastic material. The results for tool wear rate and tool wear depth, there was significant increase of 13.69 mm/sec of 57% and 0.0052 mm of 36.4% respectively as when the tool edge radius increased from 0.05 mm to 0.15 mm. Next, value for strain, stress and temperature also increased with the value of tool edge radius, where 3.63 mm/mm, 30 MPa, and 320˚C respectively. These results shows that wear of cutting tool effect the machining process and a better understanding in FEM wear simulation is important in order to improve the turning machining process.

Keywords: Simulation Analysis, DEFORM-2D, Wear, Machining

1. Introduction

Manufacturing industries can be categorized into various processes, such as rapid prototyping, machining, welding, raw material manufacturing, refining or preparation of goods. One of the major and commonly used production method in the engineering industry is metal cutting and tool wear plays an important role in the quality and effectiveness of machining [1]. Turing process is the most common in production process. Turning is the removal of metal from cylindrical work piece which attached to a rotating spindle and used to decrease the work piece's diameter, typically to a specified size, and to achieve a smooth metal finish [2].

In manufacturing industry, there is always importance to monitor the failure and tool wear in turning operation. Not to deny, there are limitations in tool wear detection. The limitations slowly overcome by

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advance technology and researches. FEM wear simulation and wear monitoring method are the often solution used. FEM wear simulation is a method where the cutting tool is model either in 2 dimensional or 3 dimensional using computer software while 2-D modeling saves time and allows the study to be performed on a standard computer, it produces less accurate results. 3-D modeling, on the other hand, produces more precise results at the expense of the capacity to operate on all systems faster [3].

Experimental and analytical approaches are still the primary ways of studying all types of wear of the cutting tool at present. However, the wear of the cutting tools is increasingly studied using numerical methods and finite element method (FEM) with the ongoing improvement of much more advance computers and numerical methods and their growing application in manufacturing anomalies in metal machining [4]. As we can see, in the coming future, the study on tool wear are expected shifting more towards using simulation as it improving, time and cost saving rather than the more conventional method.

Turning operation is a very common machining process in industry and experimental trial and observation are widely used for the optimization process of setup parameters, which are expensive and time consuming. Tool wear is continuous failure of the cutting tool due to constant use during turning process. Unfortunately, the development of tool wear causes severe friction and high tool chip where it affected the dimensional, accuracy of shape, and surface finish of the work piece [5]. The cutting wear parameter is an important factor for improving the consistency of the machined product, in order to minimize the surface roughness and increase the profit rate of the finished product. To avoid this issues, it is important to get a preliminary data through finite element simulations before the actual experiment carried out. Therefore, the aim of this study is to simulate two dimensional cutting tool wear at tool tip radius of the uncoated tungsten carbide (WC) in turning process of AISI 1045 carbon steel using finite element method and to determine the effect of stress, strain, and temperature to the changes of cutting tool edge radius.

2. Methodology

2.1 Overall Flowchart

In order to meet the study's aims, a flowchart of the methodology process has been constructed, as shown in Figure 1. This methodology has three major processes, which are as follows: Gathering data, simulation process, collect the simulation results and last but important is simulation analysis.

2.1 Materials

This machining simulation uses AISI 1045 carbon steel as the work piece. It is a low-cost alloy with appropriate strength and toughness for most engineering and construction applications. In either normalised or hot-rolled form, AISI 1045 steel is easily machinable. Machining operations on AISI 1045 steel can be performed using appropriate feeds, tool types, and speeds, according to machine manufacturer guidelines. Table 1 shows the material properties of AISI 1045 carbon steel.

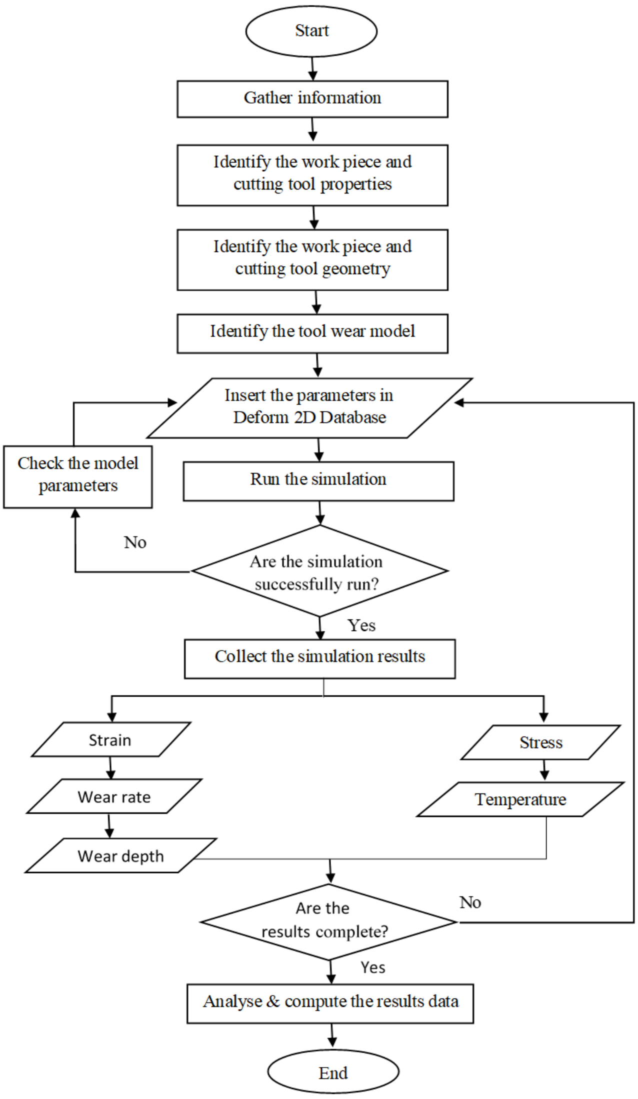

Figure 1: Methodology flowchart

Table 1: Material properties of AISI 1045 [6].

No.	Material properties	Value	Unit or Dimension
1	Density	7850	ρ (kg/m^3)
2	Elasticity	210	E (GPa)
3	Poisson ratio	0.3	v
4	Conductivity	53.9	λ (w/mK)
5	Specific heat	420	c (J/(kg.K))

Tool material was selected uncoated tungsten carbide (WC). The material properties of the cutting tools are selected directly from the DEFORM-2D library. The material properties of the cutting tool are displayed in Table 2.

Table 2: Material properties of WC [6].

No.	Material properties	Value	Unit or Dimension
1	Density	15000	ρ (kg/m^3)
2	Elasticity	800	E (GPa)
3	Poisson ratio	0.2	v
4	Conductivity	53.9	λ (w/mK)
5	Specific heat	420	c (J/(kg.K))

2.2 Simulation parameters setup

For the cutting process setup, 2D cutting is selected and the unit system set to System International (SI) unit. The setup continued with selecting the cutting speed which is 200 m/min and the feed rate set to 0.1 mm/rev. Next, the cutting condition of the machining is set which include cutting environment temperature, shear friction factor, heat transfer coefficient for the tool-work piece interface. The cutting environment temperature is set to 20˚C, and for the tool-work piece interface, the shear friction factor is 0.6 and the heat transfer coefficient is 45 N/sec/mm/C. The process setup parameters are summarised in Table 3.

Table 3: Parameters setup

Parameters	Value
Cutting speed, v (m/min)	200
Feed rate, f (mm/rev)	0.1
Environment temperature, ˚C	20
Heat transfer coefficient (N/sec/mm/C)	45
Shear friction factor	0.6

2.3 Cutting tool modelling

The first thing to model the cutting tool was to select the tool temperature which set to 20˚C and the tool geometry. The tool geometry is defined from the primitive geometry and the standard tool geometry inside the software is L1 = 1 mm, L2 = 1 mm, B = 5˚, C = 5˚, and R = 0.05 mm which shown in Figure 2. The tool mesh generation is meshed with 700 mesh in order to save time for the simulation run because the higher the mesh, the higher time for simulation. In analysis, cutting tool is assumed to be a rigid body. Geometric variables of the tool where only the tip radius, R, are altered to 0.05mm, 0.1mm, and 0.15mm. The increment of 0.05 mm is chosen from the standard geometry in the software primitive tool geometry.

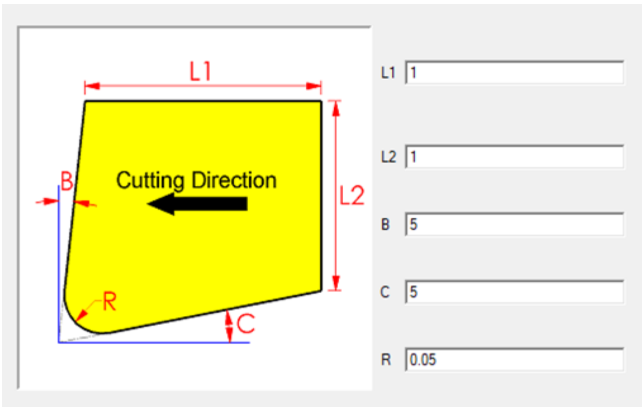

Figure 2: Primitive tool geometry.

2.4 Work piece modeling

The work piece modelling setup started with set the work piece in plastic condition and the selected temperature for the work piece is 20˚C. It is assumed that the work piece would not experience elastic deformation and will only exhibit plastic behaviour during the analysis. The work piece geometry is defined from the primitive geometry which shown in Figure 3. The size of work piece W = 4mm and H = 1mm is chosen. The generation of work piece then carried out by selecting the number of element through uncut chip thickness from the slider which is 25 that give approximately 1800 mesh.

Few last steps at the end of the pre-processing after all the parameters are inserted, there are simulation controls to select the number of step simulation, step size increment to save, length of cut for the process, and to generate the database prior for the simulation to run. For the step simulation and size of increment to save which is 10, it was remain unchanged as it predetermined by the software. The length of cut was set to half length of the work piece to decrease the time for the simulation run. After all the database is generated in the pre-processing, it is submitted to processor and after the simulation done, the results can be obtained from the post-processor.

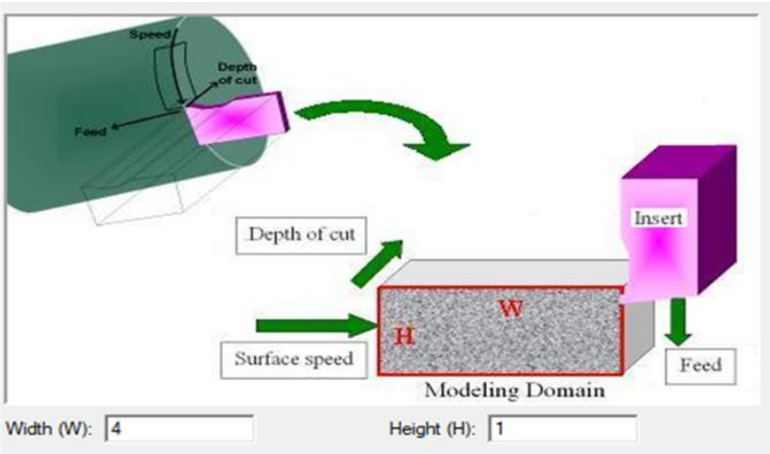

Figure 3: Primitive work piece geometry

3. Results and Discussion

3.1 Simulation Results

This section will show the results of tool wear rate, tool wear depth, work piece temperature distribution of cutting tool edge radius at 0.05mm, 0.10 mm, and 0.15 mm obtain from the simulation using the DEFORM-2D V11.0 software.

3.1.1 Tool wear rate

Table 4 and Figure 4 show the predicted results of wear rate for 0.05 mm tool which is 5.11 mm/sec. The lowest wear rate is 5.11 mm/sec of 0.05 mm edge radius tool while the highest is 18.8 mm/sec of 0.15 mm edge radius. There are 13.69 mm/sec tool wear increase of 57% between the lowest value and the highest value of tool wear rate. The increase of the tool wear rates in this study up to 57% as mention previously and this is because of the increased contact area cause by abrasion and adhesion between the cutting tool and the work piece [6].

Table 4: Results of wear rate

Edge radius (mm)	Wear rate (mm/sec)
0.05	5.11
0.1	16.9
0.15	18.8

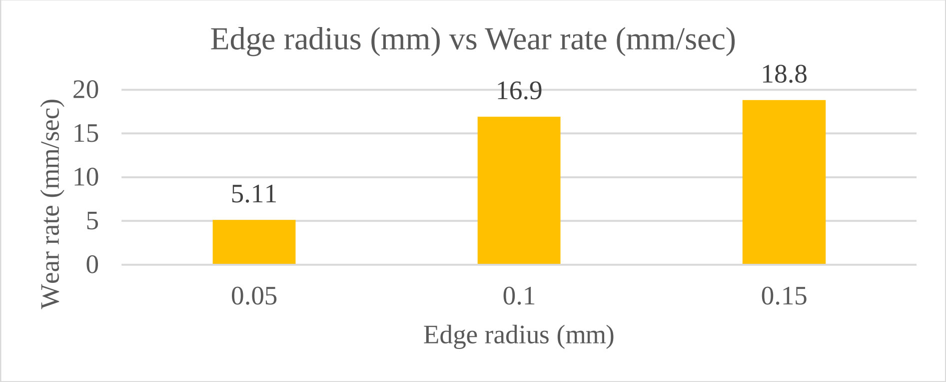

Figure 4: Edge radius (mm) vs Wear rate (mm/sec)

3.1.2 Tool wear depth

Table 5 and Figure 5 show preliminary predicted wear depth value of 0.00859 mm when the cutting simulation used 0.10 mm tool edge radius. This shows an increase of 0.00405 mm which equal 30.8% of wear depth value if compared to the lowest wear depth value of 0.00454 mm. If compared to the highest value which 0.00975 mm, there is a difference of 0.00116 mm of 6.3%. Based on the finding by other researcher this is because the wear was rapid in the first stage, gradually rose in the second stage, and drastically increased in the third stage where cutting speed and feed rate have influenced on the increase of the wear depth as the machining progress [7].

Table 5: Results of wear depth

Edge radius (mm)	Wear depth (mm)
0.05	0.00454
0.1	0.0859
0.15	0.00975

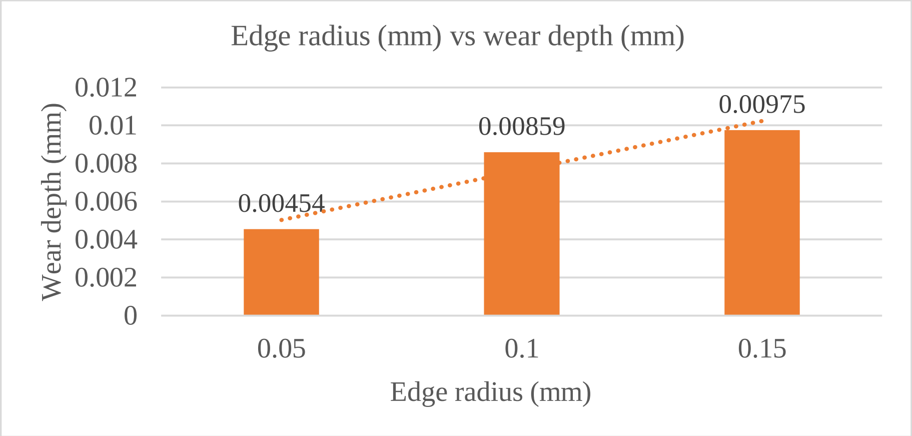

Figure 5: Edge radius (mm) vs Wear rate (mm)

3.1.3 Temperature

The results of temperature distribution are shown in Table 6 and Figure 6. The wear edge radius for simulations is in the ascending numbers of 0.05 mm, 0.10 mm, and 0.15 mm. As we can observe, among the simulations done, the highest temperature is 855°C when the wear edge radius at 0.15 mm and the lowest temperature recorded is 535°C when the edge radius at 0.05 mm. The various of contact area between the work piece and cutting tool is the conscious for the temperature increase. It can be see that; the maximum temperature occurs when the edge radius wear at the highest meanwhile the minimum temperature occurs at the lowest edge radius wear. Finding was recorded by other researchers in machining with different tool edge radius as this significant rise of the temperature on the cutting tool are because of the cutting tool crater wear [8].

Table 6: Results of temperature

Edge radius (mm)	Temperature (˚C)
0.05	535
0.1	759
0.15	855

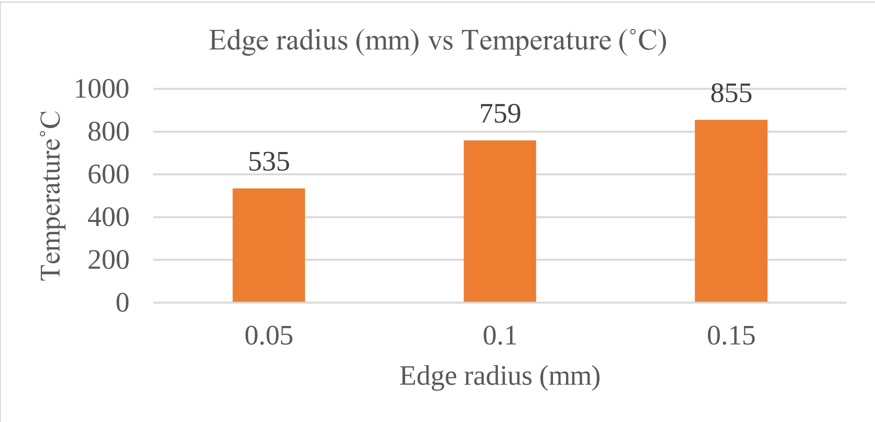

Figure 6: Edge radius (mm) vs Temperature (˚C)

3.1.4 Effective strain

From the Table 7 and Figure 7, it can be seen that the highest value of strain effective is 12.1 mm/mm, followed by 11.6 mm/mm, and the lowest value is 8.47 mm/mm. For comparison there are 3.63 mm/mm of different between the highest value and the lowest value of effective strain. The highest and lowest values of effective stress as expected were from 0.15 mm and 0.05 mm tool edge radius respectively. Hence, the increase tool edge radius has significant role that influenced the effective strain values. When the tool edge radius increase where it caused the depth of cut to increase which effect the effective strain value.

Table 7: Results of Effective strain

Edge radius (mm)	Effective strain (mm/mm)
0.05	8.47
0.1	11.6
0.15	12.1

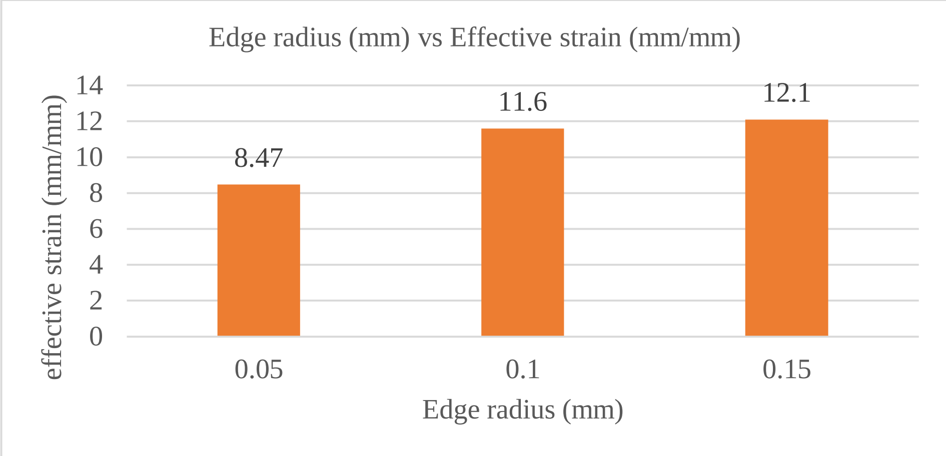

Figure 7: Edge radius (mm) vs Effective strain (mm/mm)

3.1.5 Effective stress

The predicted results for the stress effective of the simulation that effected edge radius are shown in Table 8 and Figure 8. The lowest value of preliminary result of effective stress is 1310 MPa when the cutting tool edge radius at 0.05 mm and the highest value is at 1340 MPa. There was 30 MPa of increase in the stress effective value. It can be seen that as shown in figures, the effective stress increase when the edge radius up at 0.10 mm, however the effective stress decrease when the edge radius up to 0.15 mm. This happen according to other researcher, because as the wear increase and it leads to non-uniform stress distribution [6].

Table 8: Results of Effective stress

Edge radius (mm)	Effective stress (MPa)
0.05	1310
0.1	1340
0.15	1330

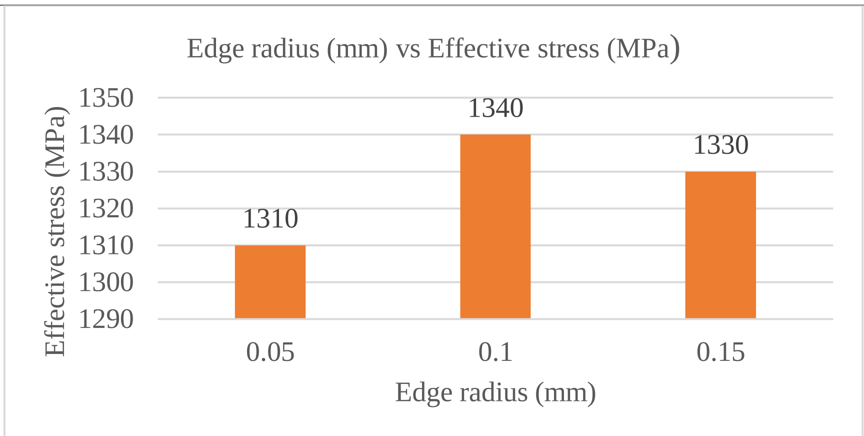

Figure 8: Edge radius (mm) vs Effective stress (MPa)

4. Conclusion

For conclusion, finite element method simulation analysis is important that can predict the preliminary data of machining accurately before the actual experiment carried out to improve the cutting condition and preparation that can help to save time and resources such as material, money and energy. Through this research, the preliminary data regarding the tool edge radius wear was successfully obtained through the simulation is using DEFORM-2D V11.0. The first objective has been achieved by successfully simulate the 2D cutting tool wear of uncoated tungsten carbide (WC) in turning process for AISI 1045 carbon steel. The results for tool wear rate and tool wear depth, there was significant increase of 13.69 mm/sec of 57% and 0.0052 mm of 36.4% respectively as when the tool edge radius increased from 0.05 mm to 0.15 mm. Next the effect of stress, strain, and temperature to the changes of cutting tool edge radius was successfully determined. The value for strain, stress and temperature also increased with the value of tool edge radius, where 3.63 mm/mm, 30 MPa, and 320˚C respectively. These results show that changes of cutting tool radius effect the machining process. With this, the second objective was also successfully achieved. As recommendation, experimental work as the future work to validate the preliminary data obtained from the simulation.

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References

[1] Sharma, V. S., Sharma, S. K., & Sharma, A. K. (2008). Cutting tool wear estimation for turning. Journal of Intelligent Manufacturing, 19(1), 99–108

[2] Trent, E. M., & Wright, P. K. (2000). Metal cutting operations and terminology. Metal Cutting, 9–20

[3] Asad, M., Mabrouki, T., Ijaz, H., Aurangzeb Khan, M., & Saleem, W. (2014). On the turning modeling and simulation: 2D and 3D FEM approaches. Mechanics and Industry, 15(5), 427–434.

[4] Xie, L. J., Schmidt, J., Schmidt, C., & Biesinger, F. (2005). 2D FEM estimate of tool wear in turning operation. Wear, 258(10), 1479–1490.

[5] Grzesik, W. (2009). Wear development on wiper Al2O3-TiC mixed ceramic tools in hard machining of high strength steel. Wear, 266(9–10), 1021–1028.

[6] Shi, Z., Li, X., Duan, N., & Yang, Q. (2021). Evaluation of tool wear and cutting performance considering effects of dynamic nodes movement based on FEM simulation. Chinese Journal of Aeronautics, 34(4), 140–152.

[7] Sein, A. K., Htwe, E. E., & San, N. A. (2015). Investigation of Stress Formation and Wear Effect of Tool by Finite Element Simulation. American Journal of Mechanical Engineering, 3(5), 147–154.

[8] Özel, T., & Zeren, E. (2005). Finite element method simulation of machining of AISI 1045 steel with a round edge cutting tool. Proceedings of the 8th CIRP International,September.https://www.researchgate.net/profile/Tugrul_Ozel/publication/260021782_Finite_Element_Method_Simulation_of_Machining_of_AISI_1045_Steel_With_A_Round_Edge_Cutting_Tool/links/0046352f1b9)