Yanbu Journal of Engineering and Science

Volume 21 | Issue 1 Article 7

2024

STRESS, EQUIVALENT STRAIN AND DEFORMATION FOR MACHINING OPERATION UTILIZING EXPLICIT DYNAMIC ANALYSIS FOR VARIOUS MATERIALS

Anand Valiavalappil
Mechanical Engineering and Technology, Royal Commission for Jubail and Yanbu

Follow this and additional works at: https://yjes.researchcommons.org/yjes
The journal in which this article appears is hosted on Digital Commons, an Elsevier platform.

Recommended Citation
Valiavalappil, Anand (2024), STRESS, EQUIVALENT STRAIN AND DEFORMATION FOR MACHINING OPERATION UTILIZING EXPLICIT DYNAMIC ANALYSIS FOR VARIOUS MATERIALS, *Yanbu Journal of Engineering and Science*: Vol. 21: Iss. 1, 1-8.
DOI: https://doi.org/10.53370/001c.94740
Available at: https://yjes.researchcommons.org/yjes/vol21/iss1/7

This Research Article is brought to you for free and open access by Yanbu Journal of Engineering and Science. It has been accepted for inclusion in Yanbu Journal of Engineering and Science by an authorized editor of Yanbu Journal of Engineering and Science.

Research article

STRESS, EQUIVALENT STRAIN AND DEFORMATION FOR MACHINING OPERATION UTILIZING EXPLICIT DYNAMIC ANALYSIS FOR VARIOUS MATERIALS

Anand Valiavalappil[1]

[1] Mechanical Engineering and Technology, Royal Commission for Jubail and Yanbu

Keywords: Machining using CNC, FEA (Finite Element Analysis) using Ansys for different material, John Cook Constitutive Model

https://doi.org/10.53370/001c.94740

Yanbu Journal of Engineering and Science

Vol. 21, Issue 1, 2024

Abstract

Subtractive and additive manufacturing methods constitute the two main categories of modern manufacturing technology used in the manufacturing sector. The subtractive method is used for material removal and is performed in (Brass, Aluminum and Teflon), the machining process is achieved using CNC (Computer Numerical Method) turn machine.

The main objective of the paper is to perform FEA (Finite Element Analysis) over the three material (Brass, Aluminum and Teflon). The CNC machine is used to perform a machining over the three-material stated above, but within the CNC machine there is no provision for achieving the various values of (stress, strain and deformation) during the machining operation. During the machining process, it's very difficult to get and accurate value of stress for the tool and raw (test) material, so Ansys FEA analysis method is adopted to predict the parameter like stress, strain and total deformation. The analysis part is achieved by the developing the CAD model using Solid work and FEA analysis using Ansys and thereby the output will be helpful to understand the various stress parameters.

The results highlight that Teflon has a higher value for total deformation followed by aluminum and brass. The equivalent strain for the Teflon is higher and followed by brass and aluminum. The stress is acting in axial and compressive direction, so brass have a higher value followed by aluminum and Teflon. This method and analysis procedure can be adopted for understanding the deformation, stress and stain acting on any material, which will be highly useful for material of higher with a higher hardness value.

1. INTRODUCTION

The design process relies heavily on modelling as its backbone, employing various methods within this process. The finite volume method (FVM), the finite element method (FEM) and the 3D image process are a few of the technique utilized in the modeling and analysis process.[1] When utilized appropriately, FEM is the most widely used computer-based technique for comprehending metal removal and is thought to be reasonably accurate.[2] The simulation and analysis-driven results provide a good and verified output using FEM.[3]

The temperature generated during the machining process plays a vital role in surface roughness and tool life span, and also it affects the dimensional accuracy of the machined components. Within this paper, the machining process is carried out as a dry cut as it is considered to be the cleanest manufacturing technique.[4] There are good results obtained for machining the aluminum using the HSS tool which reveals that the temperature obtained during a few cycles at the beginning of machining gradually comes to a steady-state.[5] This paper not only focuses on aluminum as the raw material for machining but also brass and Teflon since Teflon is used mostly for the prototype and initial testing for the product development.

Using Ansys software, the FEM (explicit dynamics) based analysis gives a variety of cutting parameter, including data for (Total deformation, shear stress and equivalent elastic strain) etc. These mentioned values are not measured directly, but these values are very essential to provide an insight depth for the machining process along with wear analysis.[6] The FEM method is very important since some values cannot be easily evaluated using the machining process.[7]

There are mainly two ways in which the friction is taken into consideration during the machining process: sliding and adhesion friction. The understanding of friction and its effect on the tool temperature is critical during the machining process.[8] In general, three-levels of friction factors are taken into consideration as (0.6, 0.8, and 1.2). The value is

always directly proportional to the tooltip temperature and thereby the tool wear. Ansys FEA is used to produce the FEM based (Explicit Dynamic) analysis, and the John cook constitutive model is used for the working material. That enables the damage within the workpiece to be analyzed at the highest possible range. According to the study, the rake angle increases in direct proportion to the cutting force,[9] meaning that during the machining process the rake will always be precisely the same when analyzed using a computer.

The cutting material used is an HSS tool and its shape also has a significant effect during the machining process,[10] the cutting insert shape used for machining is a diamond and also modeled as the same. The tool can get significantly worn out by the flank, and according to some researchers the flank wear is considered to be parallel with the material removal direction,[11,12] and for some researchers, it's just a non-zero angle for the material removal direction.[13-15] The latest experimental study revealed that flank wear inclination is very important and also shows effects for the different tool forces.[16] The non-zero angle was revealed as 3.8 degrees, and the angle used in experimental and analysis work was 3.5 degrees. There are also studies in which the temperature distribution also depends on the flank wear length,[17] so during the simulation, the wear length will be considered to be maximum as per the diamond cutting tool. The air cooling during the metal cutting process is also studied, in which the temperature distribution within the tooltip has minor significance[18] so in this study, it's not considered during simulation.

Three materials- Aluminum, Brass and Teflon- are taken into consideration for machining in this study. Total deformation, shear stress and equivalent elastic strain distribution for the length of workpiece are derived by simulation, and a comparison is made using graph.

2. PROPOSED METHODOLOGY

The following approaches are used to execute out and apply the methodology: Ansys analysis and the machining process. The workpiece made of (Aluminum, Brass and Teflon) is machined in the first phase, and it can be challenging to calculate the total deformation, shear stress and equivalent elastic strain. A second phase of the FEA will be supplied by the Ansys program; as a result, different value of total deformation, shear stress and equivalent elastic strain can be obtained, and a graph will be used to provide a comparison.

3. MACHINING INTRODUCTION

The machining process is created using CNC Turn Machine 155, using the sinumerick language. The program is created using EMCO Concept software, for an 810/840D CNC turn machine.

The emco concept software is used to design the CAD geometry and various cutting parameters are included for the machining. This includes feed rate, speed, infeed relief

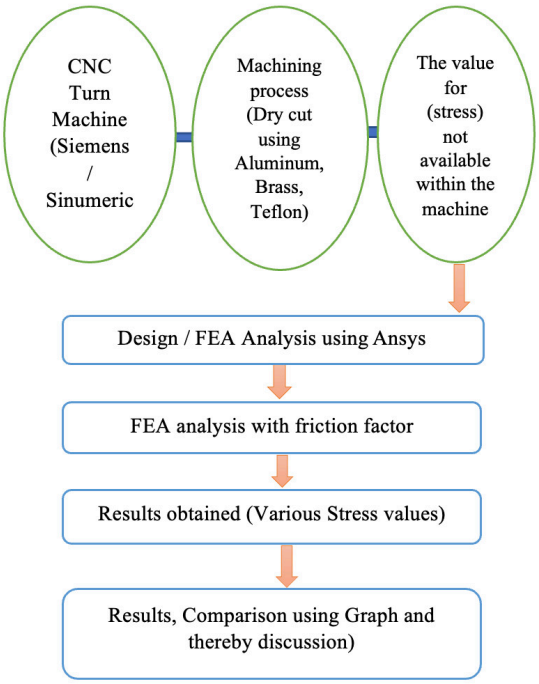


Figure 1. Machining and Analysis procedure

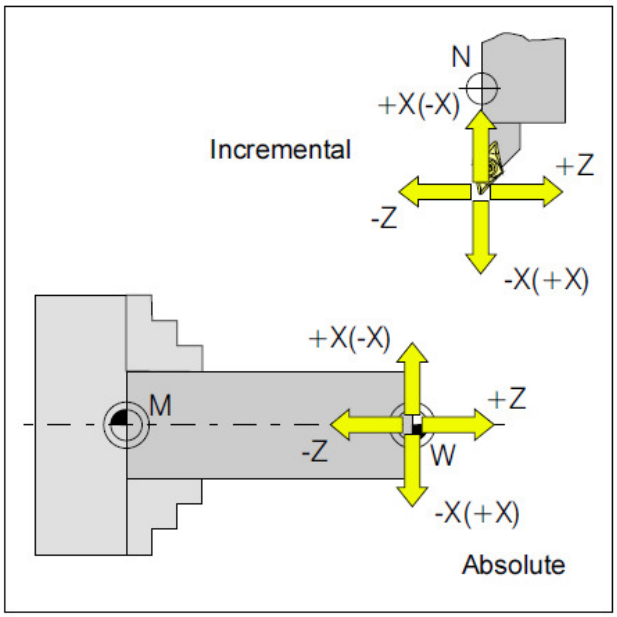


Figure 2. CAD with tool position

angle, and also dry cut. An explanation of the CAD diagram with tool position is shown in figure 2

For cutting the workpiece a diamond shaped insert is inserted into the tool to produce a high surface finish. This will be helpful for the tool and workpiece for achieving a better life cycle during the machining process.

The CAM technique will be applied to the CAD diagram which was generated with the software, and as an outcome, the machine code and geometric data will be exported to the computer numerical control (CNC) controller for simulation before being machined.

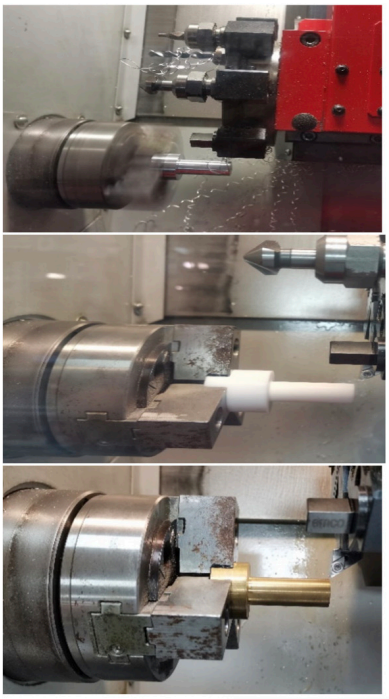


Figure 3. CNC Machine cutting workpiece for different materials (Aluminum, Teflon and Brass) followed from (Top to down)

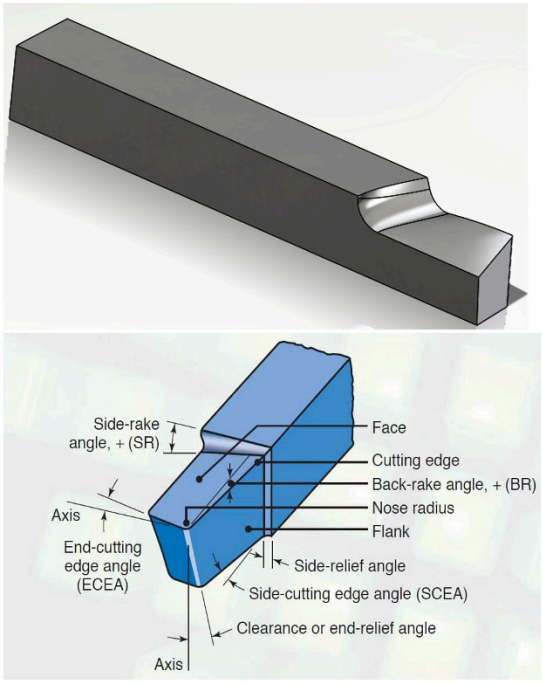


Figure 4. Single point cutting tool using solid work

Aluminum, Brass and Teflon are the materials used for cutting; the diagram below will help to understand the machining and tool utilized.

The speed (1000 rpm) and feed (0.2 mm/rev) are maintained the same for all the cutting workpiece, and the depth of cut is 1mm and used same for analysis in Ansys software.

4. DESIGN AND ANALYSIS

The different stress and strain parameters present in the tool and for the workpiece cannot be better understood during the machining process. Software can accomplish this, hence Ansys FEA (Explicit Dynamics) analysis is used in this situation.

4.1. BRIEF OVERVIEW OF FEA ANALYSIS USING ANSYS

The analytical methods provide solutions for the unknown quantity in any region of the body, but these solutions can only be applicable to different points or places within the body that are being considered. Therefore, this method is difficult for applying in a more complex engineering concept for a body under various types of forces. The solution for such a kind of problem is to adopt the FEA analysis, and for this work the software used is Ansys.

4.2. CAD DIAGRAM FOR SINGLE POINT CUTTING TOOL

The CAD geometry is considered to be the starting point for any kind of analysis. Therefore, various types of software used for this purpose are (AutoCAD, ProE, Solid work, etc.). This work features a CAD schematic created with solid work

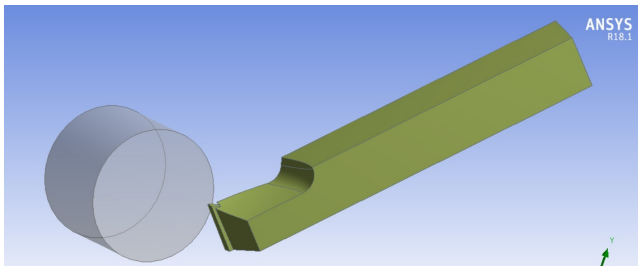


Figure 5. Tool insert with workpiece

that shows the workpiece and single point cutting tool. The single point tool is created using the various values such as (Rake face length of 3cm, Flank Length of 2cm, clearance, and rake angle of 6 degrees each) as shown in the diagram.

Figure 3, will provide a better understanding of the tool used and figure 5 shown below will provide a workpiece along with a cutting tool insert. The combined bodies are exported within the Ansys workbench and further for analysis. The tool inserts used has the following parameters, and while designing it was implemented as (edge angle 55˚, edge width 7.750 mm, cutting angle 93˚, and tool radius 0.4 mm). These values are adopted from tool insert and also used in the analysis purpose and thereby the stress measured using analysis software will have an accurate result. The tool used is a left-hand side tool (LHST) so the machine has a spindle running direction is counterclockwise.

4.3. MATERIAL FOR MACHINING

The three materials used for analysis purposes, such as Brass, Aluminum, and Teflon and the insert are High-speed steel (HSS). The data for aluminum is available within the

Table 1. ANSYS Material Library Aluminum Alloy Material Properties,[21]

Property	Aluminum Alloy	Unit
Density	2770	kg m^-3
Young's Modulus	71000	MPa
Poisson's Ratio	0.33	
Bulk Modulus	69608	MPa
Shear Modulus	26692	MPa
Yield Strength	280	MPa
Tensile Ultimate Strength	310	MPa

database of Ansys software, also for the brass but for Teflon values are to be incorporated. The different mechanical values for Teflon are found and added in the Ansys workbench.[19,20] Among the three chosen materials, Brass is the hardest and aluminum is mildly hard and the Teflon is used for machining and analysis as it's used for prototypes and less hard than the other two.

4.4. DESIGN AND FEA ANALYSIS

The cutting tools design and analysis provide the ideal value for machining, which is within the flank wear lands 8-degree incline.[22] For both simulation and design the value is maintained constant. The major factor for surface roughness is the friction between the tool and the workpiece, according to the study an optimum value of 0.4 was obtained and failure for the tool and workpiece are enhanced for FEA analysis using the Johnson-Cook model.[23] The analysis is created using explicit dynamics, which will be helpful for getting different stress values. This can be adopted in simulation work where a short duration of product failure occurs for a transient dynamic force.

Figures 6, 7, and 8 provide an insight concept for explicit dynamic analysis, three values are found for each material (Aluminum, Brass, and Teflon) as (Total deformation, Shear stress and Equivalent elastic strain).

The mesh size in FEA analysis is refined to the maximum in Ansys workbench to achieve more accurate results. The temperature contour cannot be plotted using Ansys explicit dynamics as there is no option within the software.

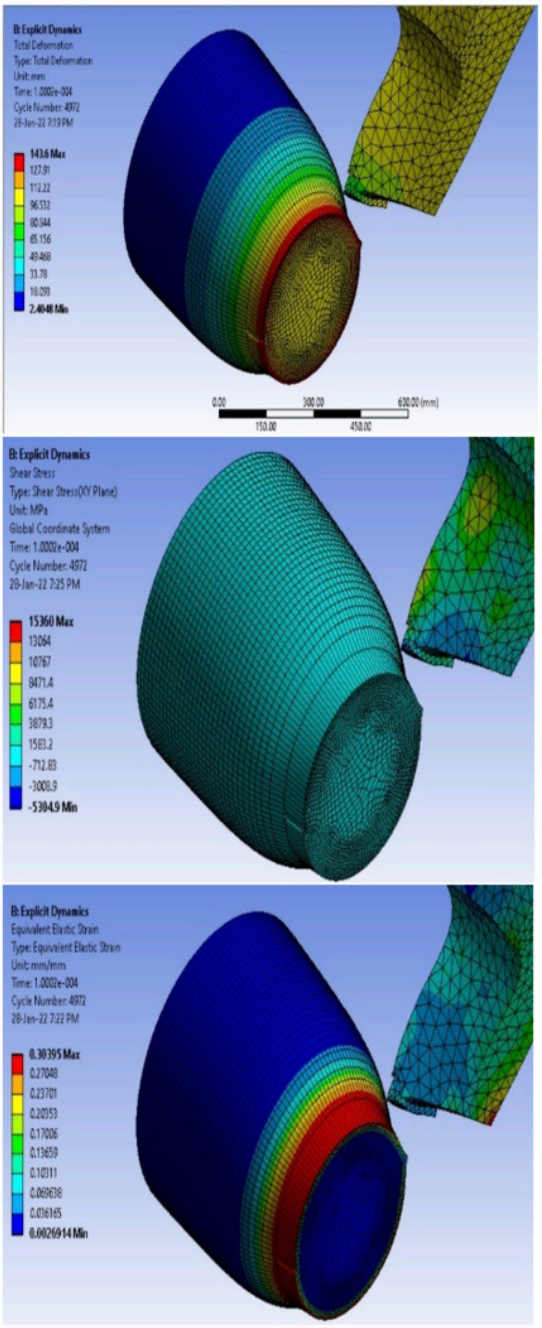


Figure 6. Ansys Explicit dynamic Analysis (Total deformation, Shear stress and Equivalent Elastic strain) for Aluminum followed from (Top to down)

5. RESULT AND DISCUSSION

When it involves machining and obtaining values that provide high-quality product output, the procedure is always complex. The machining performed over the three materials have the same feed rate and speed. The force acting over the material differs as the hardness of the material is different. The amount of stress acting over the tool and workpiece is really difficult to be measured using the current setup within the machine. To compensate for these particular criteria the CAD is created and thereby the stress acting within the workpiece and tool is measured. The three values are discussed within this paper, as the software can create only three of them within the explicit dynamic analysis.

The values obtained within the analysis for total deformation can be observed from the graph plotted. The values differ for each raw material under consideration, when the comparison is created it's clearly visible that Teflon has a higher value and which is followed by aluminum and the last as brass. The values are higher as the Teflon hardness is less compared to the other two materials. The same phenomenon can be observed during machining also, the machinability of Teflon is sizeable and appreciable when

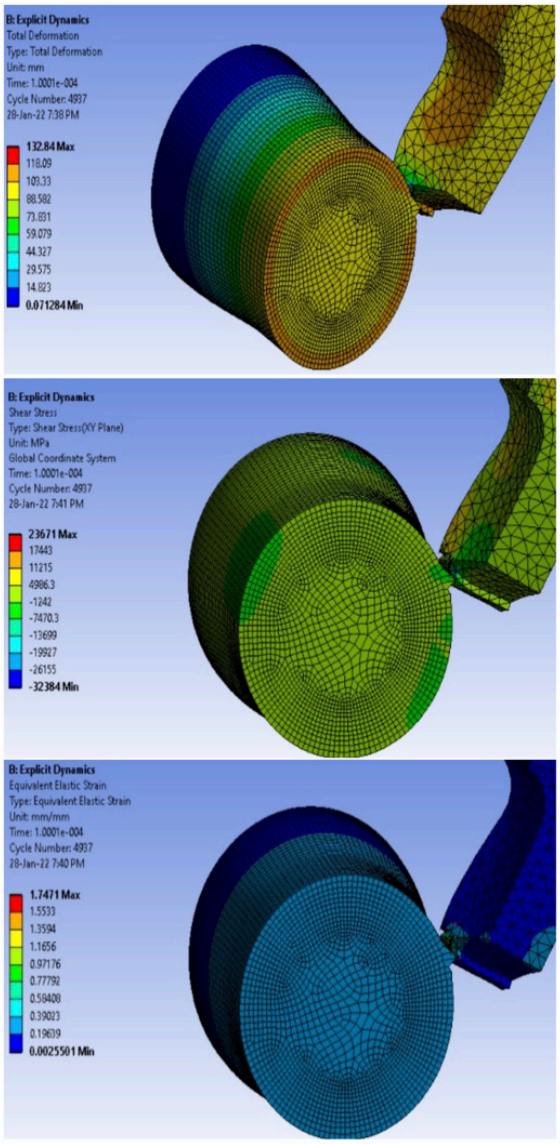


Figure 7. Ansys Explicit dynamic Analysis (Total deformation, Shear stress and Equivalent Elastic strain) for Brass followed from (Top to down)

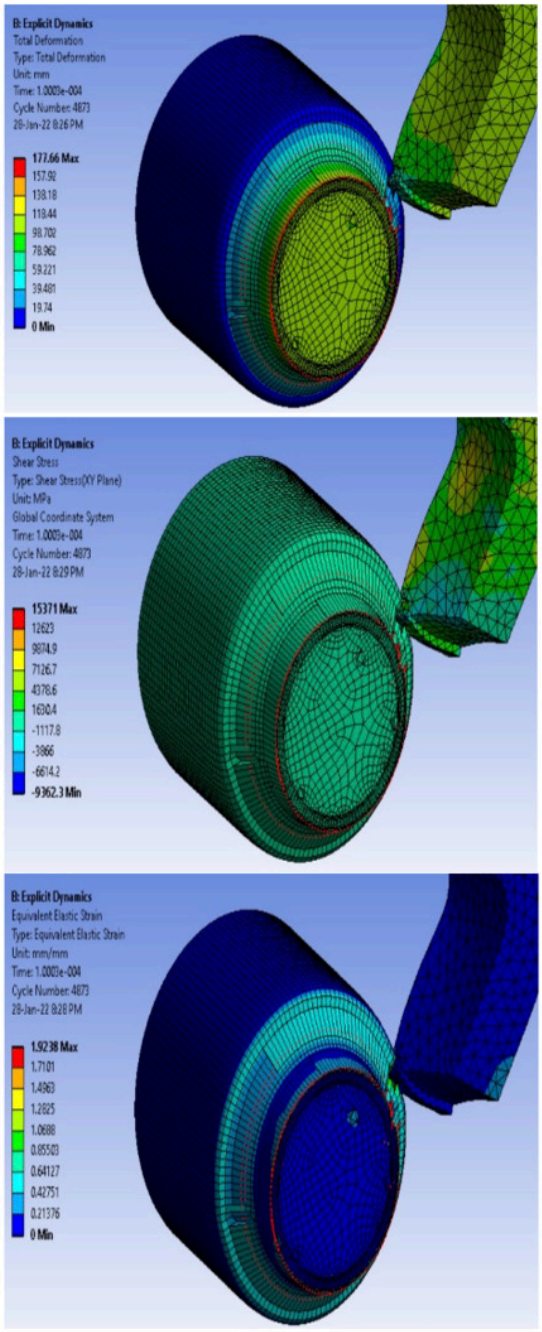


Figure 8. Ansys Explicit dynamic Analysis (Total deformation, Shear stress and Equivalent Elastic strain) for Teflon followed from (Top to down)

compared to the other two materials. Teflon is used as a prototype material, so it's worth is considered to be only for pre-production purposes.

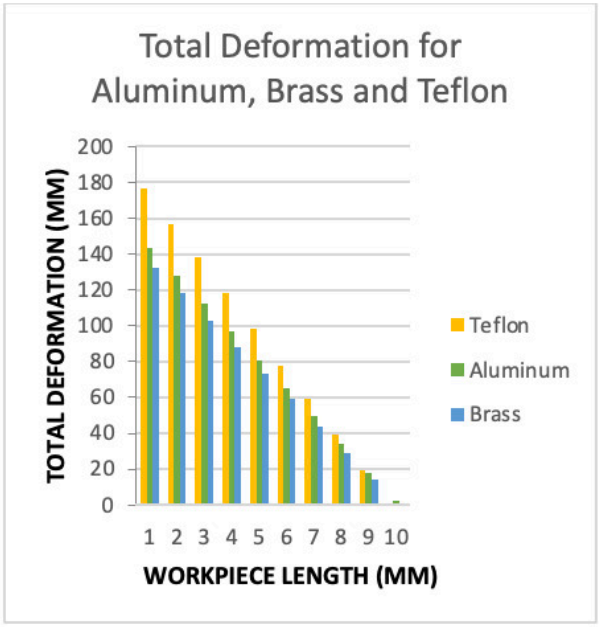
The equivalent strain or the von mises equivalent strain is also a very important factor that affects the raw material, each material point within the region of a product has a strain rate and which is calculated in Ansys software as a strain tensor. The equivalent strain for the Teflon is higher and followed by brass and aluminum.

The last value obtained from the Ansys analysis is the shear stress, the value obtained is very useful as this force causes the deformation of the material by rubbing or cutting the workpiece. This force always acts along the plane which is parallel to the imposed stress. This value can either be a positive or a negative, the positive value when the axial stress acting is considered to be tensile, whereas its negative when the force acting is considered to be compressive in nature. It can be observed from the graph that the value is positive as well as negative, as there is both tensile and compressive stress acting while the machining process is achieved.

6. CONCLUSION

The effect of machining within the cutting direction is studied using ANSYS FEA explicit dynamics analysis. The three important values have a significant effect on the tool and also the workpiece.

The total deformation value is higher for Teflon so the feed rate can be increased and machinability can be



Graph 1. Total deformation Vs workpiece length

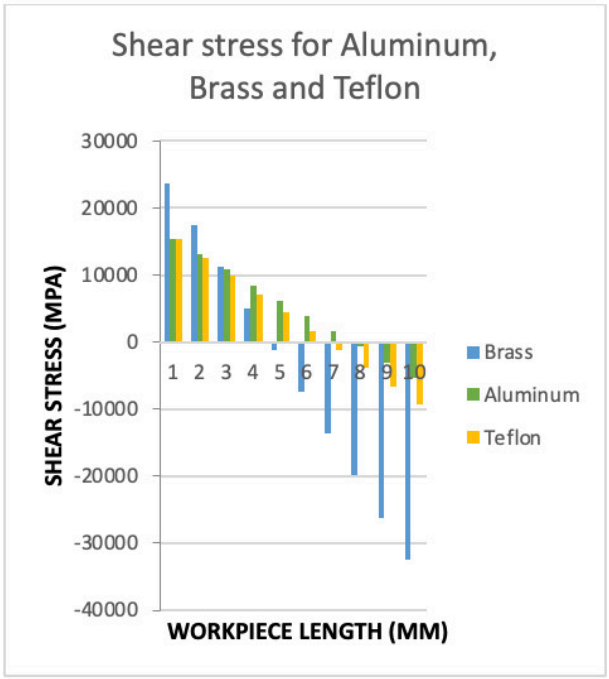


Figure 10. Shear stress Vs workpiece length

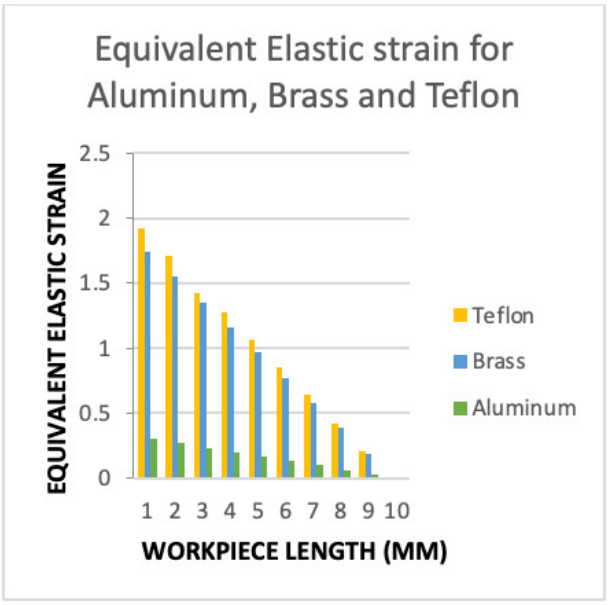


Figure 9. Equivalent elastic strain Vs workpiece length

achieved within the lead time, whereas the aluminum is having a moderate value so the feed rate needs to be reduced, and thereby the tool life can be increased and the machinability time will be increased. The brass is having the least value so both the tool life and lead time need to be carefully checked before proceeding to dry machining.

The equivalent strain is more for Teflon and thereby followed by brass and aluminum. These values are very important as the region for maximum value will be very useful for further study and analysis. The value of shear stress is vitally important for further research for the production and machining industry for achieving a better tool life and also to maximus the lead time.

These three values will be really helpful for the industry to produce the cutting tool according to the material and also to achieve a better surface finish.

Submitted: July 16, 2023 AST, Accepted: January 03, 2024 AST

This is an open-access article distributed under the terms of the Creative Commons Attribution 4.0 International License (CCBY-4.0). View this license's legal deed at http://creativecommons.org/licenses/by/4.0 and legal code at http://creativecommons.org/licenses/by/4.0/legalcode for more information.

REFERENCES

1. Trent E, Wright P. *Metal Cutting*. 4th ed. Publisher unknown; 2000.

2. Zienkiewicz OC. *The Finite Element Menthod: Its Basic and Fundamental*. 6th ed. Elsevier Butterworth-Heinemann Linacre; 2005.

3. Lungu N, Borzan M. Effect of cutting speed and feed rate on tool geometry, temperature and cutting forces in machining AISI 1045 carbon steel using FEM simulation. *Proceedings in Manufacturing Systems*. 2012;7(4):245-255.

4. Bagaber SA, Yusoff AR. Multi-objective optimization of cutting parameters to Minimize power consumption in dry turning of stainless steel 316. *Journal of Cleaner Production*. 2017;157:30-46. doi:10.1016/j.jclepro.2017.03.231

5. Stephenson DA, Ali A. Tool Temperatures in Interrupted Metal Cutting. *ASME J Eng Ind*. 1992;114(2):127-136. doi:10.1115/1.2899765

6. Yen YC, Söhner J, Lilly B, Altan T. Estimation of tool wear in orthogonal cutting using the Finite element analysis. *Journal of Materials Processing Technology*. 2004;146(1):82-91. doi:10.1016/s0924-0136(03)00847-1

7. Yen YC, Söhner J, Lilly B, Altan T. Estimation of tool wear in orthogonal cutting using the Finite element analysis. *Journal of Materials Processing Technology*. 2004;146(1):82-91. doi:10.1016/s0924-0136(03)00847-1

8. GÖK K, GÖK A, Erdem M. Effect of friction coefficient in tool-workpiece interface during metal cutting. *Engineering e-Transaction*. 2011;6(1):32-33.

9. Khalili K, Safaei M. FEM analysis of edge preparation for chamfered tools. *Int J Mater Form*. 2009;2(4):217-224. doi:10.1007/s12289-009-0405-0

10. Yen YC, Söhner J, Lilly B, Altan T. Estimation of tool wear in orthogonal cutting using the Finite element analysis. *Journal of Materials Processing Technology*. 2004;146(1):82-91. doi:10.1016/s0924-0136(03)00847-1

11. Uysal A, Altan E. A New Slip-Line Field Modeling of Orthogonal Machining for a Worn Tool. *International Symposium on Models and Modeling Methodologies in Science and Engineering: MMMse*. 2011;3:193-198.

12. Kountanya RK, Endres WJ. Flank wear of edged radiused cutting tools under ideal straight edged orthogonal conditions. *Tran of the ASME*. 2004;126(3):496-505. doi:10.1115/1.1765148

13. DAS NS, Dundur ST. Slip line field solutions for metal machining with adhesion friction and elastic effects at the chip-tool contact region. *Proc IMECH part B j Engg Manufacture*. 2005;219(1):57-71. doi:10.1243/095440505x8091

14. Shi T, Ramalingam S. Slip-line solution for orthogonal cutting with a chip breaker and flank wear. *International Journal of Mechanical Sciences*. 1991;33(9):689-704. doi:10.1016/0020-7403(91)90065-b

15. Long Y, Huang Y. Combined effects of flank and crater wear on cutting force modeling in orthogonal machining -Part-1: model development, Machining science and technology. *Machining Science and Technology: An Int Journal*. 2010;14(1):1-23. doi:10.1080/10910341003676992

16. Jaharah AG, Wahid SW, Che Hassan CH, Nuawi MZ, Rahman MA. The Effect of uncoated carbide tool geometries in turning AISI 1045 using Finite element analysis. *European journal of scientific research*. 2009;28(2):271-277.

17. KOHIR VV. Finite Element Simulation to study the effect of flank wear land inclination on Cutting forces and temperature distribution in orthogonal machining. *JEF*. 2014;1(1):30-42. doi:10.17530/jef.14.04.1.1

18. Pervaiz S, Deiab I, Wahba EM, Rashid A, Nicolescu M. A Coupled FE and CFD Approach to Predict the Cutting Tool Temperature Profile in Machining. *Procedia CIRP*. 2014;17:750-754. doi:10.1016/j.procir.2014.01.104

19. Nunes LCS, Dias FWR, da Costa Mattos HS. Mechanical behavior of polytetrafluoroethylene in tensile loading under different strain rates. *Polymer Testing*. 2011;30(7):791-796. doi:10.1016/j.polymertesting.2011.07.004

20. Dielectric Manufacturing. Material Properties of Teflon - Polytetrafluoroethylene (PTFE). Dielectric Manufacturing, Dielectric Manufacturing. November 19, 2021. https://dielectricmfg.com/knowledge-base/teflon/

21. ANSYS® Academic, Release 17.0 Computer Software Material Library

22. KOHIR VV, Vishaldatt V, DUNDUR ST. Finite Element Simulation to Study the Effect of Flank Wear Land Inclination on Cutting Forces and Temperature Distribution in Orthogonal Machining. *JEF*. 2014;1(1):30-42. doi:10.17530/jef.14.04.1.1

23. Pervaiz S, Deiab I, Wahba EM, Rashid A, Nicolescu M. A Coupled FE and CFD Approach to Predict the Cutting Tool Temperature Profile in Machining. *Procedia CIRP*. 2014;17:750-754. doi:10.1016/j.procir.2014.01.104