Progress in Engineering Application and Technology Vol. 3 No. 1 (2022) 840-848

PEAT

Homepage: http://publisher.uthm.edu.my/periodicals/index.php/peat
e-ISSN : 2773-5303

Investigation of Rectangular Pocket Machining Simulation Using Design of Experiments (DOE)

Shamsuddin Mahmood[1], Azli Nawawi[1]*, Wan Mohd Wardi Wan Abdul Rahman[1]

[1]Department of Mechanical Engineering Technology, Faculty of Engineering Technology, Universiti Tun Hussein Onn Malaysia, 84600 Pagoh, Johor, MALAYSIA

*Corresponding Author Designation

DOI: https://doi.org/10.30880/peat. peat.2022.03.01.083
Received 17 January 2022; Accepted 11 April 2022; Available online 25 June 2022

Abstract: Design and finite element method (FEM) is a commonly utilized procedure in large volume manufacture of components. The numerous product designs and materials utilized in manufacturing to generate prototypes and commercial items today highlight the competition and tough situations involved in generating a viable product for marketing. The major purpose of this research is to describe the construction of a model by employing the Design of the experiment (DOE). The model explores the influence of various characteristics on the product design of RPM. This helps in determining the process leading parameters for similar items created from four different materials with a tolerable quality on the same design and machining process. The finite Element Method (FEM) and Design of Experiments (DOE) technique are utilized in order to accomplish the specified model goals. It can be claimed that the Finite Element Method with Design of Experiments technique gives a good contribution towards the optimization of the material in building and design for the optimum purpose of the process in manufacturing technology. The creator or designer will face challenges in terms of design, material selection, tooling selection, process selection, and prototype creation in order to capitalize on market trends. The study is more concerned with the machining process than with product design and material analysis by using finite elements in Solidworks can have a significant impact or effect on the machining process, particularly when using a milling machine with computer numerical control .The structure, VonMises, displacement, and strain with different forces and mechanical loading are used to determine the path of material with yield strength. A comprehensive framework for design and finite element analysis with the implementation of Doe will improve the efficiency of the product design and machining process.

Keywords: Finite element method, Design of experiment (DOE), Solidworks

Corresponding author: azle@uthm.edu.my

1. Introduction

Designing using Solidworks is a common practice in large-scale manufacturing of a broad range of components. There are general recommendations for this procedure, but they are not adequate to overcome the obstacles in developing products and processes, where the need for a shorter cycle time and more precise product dimensions becomes increasingly critical [1]. It is still common for industrial Rectangular Pocket Milling process design to be heavily reliant on experimental work, with costly and time-consuming iterations as a result of the relatively little amount of information available about these processes [2].

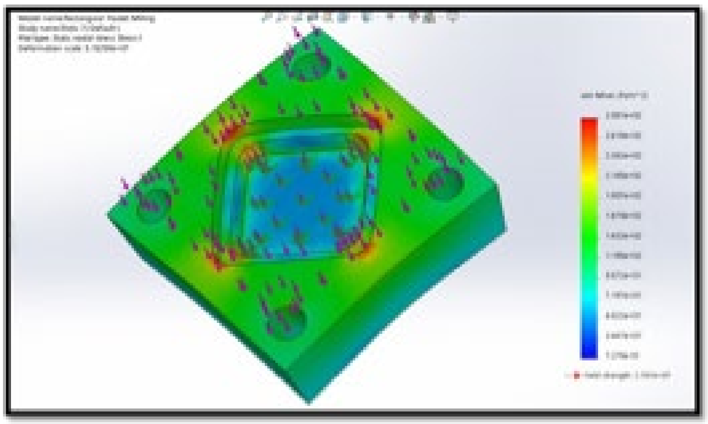

Figure 1: FEA Aluminium alloy 1060 Yield strength

One strategy that might be used in this study to optimise a key parameter for the machining process on a CNC machine is the design of experiments.[4], [5] Figure 1.0 show the finite element analysis of the material aluminium alloy 1060 for yield strength, the RPM process design requires a novel approach that eliminates the need for trial and error. Because of this, accurate modelling and knowledge of the RPM process might help save production times and maintain tight control over product requirements, particularly form. Current operations control research strives to increase component quality investigation and monitoring and control. Because of the high cost of tools that need to be replaced after catastrophic failure and the decrease in reject parts and manual quality control, this is a must[5], [6]. Maintenance and operations of production lines are directly impacted by improvements in manufacturing processes and parameter control. Finite element technique and DOE are two of the most essential technologies for optimising manufacturing processes (FEM).

Using a mix of both methodologies, this article aims to obtain a greater degree of verification while also reducing costs associated with testing[7], [8]. As a result, pricey dies will not be created until the finite element approach displays the optimal combination of the process parameters at their stipulated levels. Design of trials will assist in this process. The developed experimental investigation of the RPM model process makes it possible to study the effects of process parameters such as the material analysis by using SolidWorks, especially by the Doe approach. The finite element and design of experiments methods are used in order to obtain a better understanding of the manufacturing response error or missing element[9], [10]. The process signatures indicate that the material types as well as the structural characteristics of the tools and their configuration parameters influence the upgrade and making of the manufacturing process, which will reduce the cost effectively[3], [11].

The manufacturer will utilize the milling process to eliminate any undesirable materials. Dimensionally and geometrically accurate, with a high-quality polish. Milling is used as a corrective machining process to ensure that exceptional and high-quality composite manufacturing is achieved [12].

2. Materials and Methods

2.1 Materials

Traditionally, precision machining has concentrated on geometrical aspects of machined components, such as dimensional accuracy and surface roughness[5], [13]. Table 1.0 Properties: Specific Material Aluminium Alloys – 1060 show from Solidworks 2019. The dimensional accuracy of machined components is greatly influenced by tool wear and deflection. Surface roughness is influenced by process factors such as cutting speed, feed rate, and tool shape edge radius, rake angle[14].

Table 1: Properties specific material aluminium alloys – 1060

No	Aluminium Alloys 1060	value
1	Elastic Modulus	6.90E+10
2	Poisson's Ratio	0.33
3	Shear Modulus	2.70E+10
4	Mass Density	2700
5	Tensile Strength	68935600
6	Compressive Strength	
7	Yield Strength	27574200
8	Thermal Expansion Coefficient	2.40E-05
9	Thermal Conductivity	200
10	Specific Heat	900
11	Material Damping Ratio	

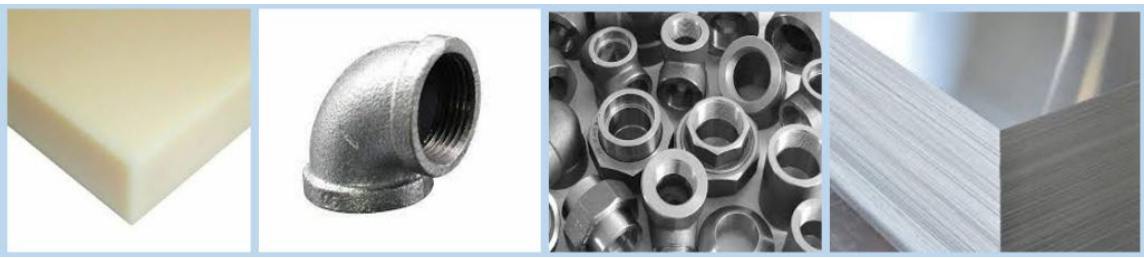

Figure 2: Type of material analysis by SolidWorks

Figure 2 shows 4 types of material analysis by using method FEA SolidWorks software. Other aspects of the machining end-product, such as surface physical properties, metallurgy, tooling, and treatment, are also included in precision machining[6], [14]. The surface residual stress profile may affect the fatigue life and corrosion resistance of a workpiece[15].

2.2 Methods

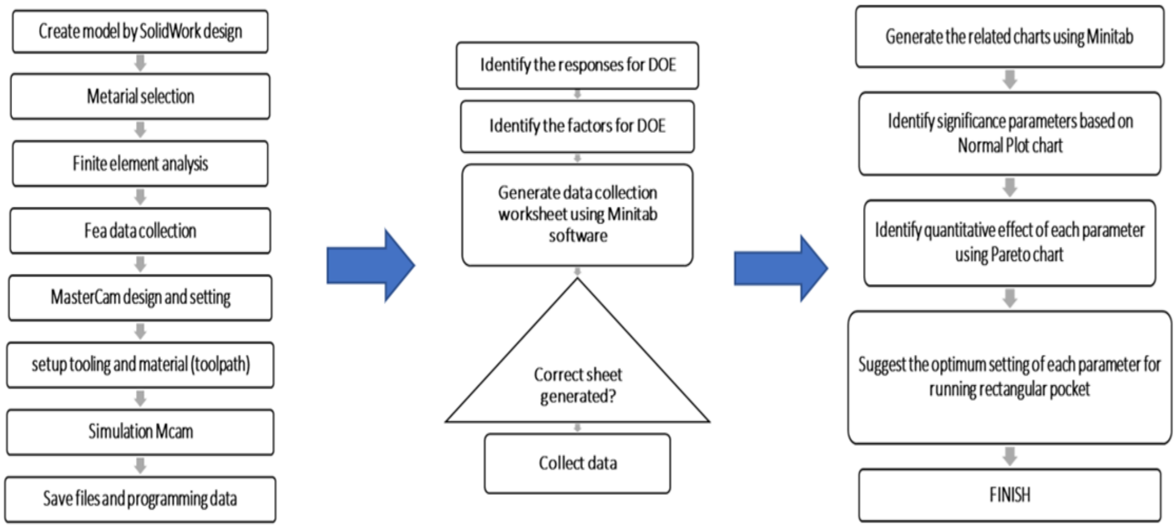

Figure 3: Methodology flowchart for performing DOE analysis on RPM results

Figure 3 above show the methodology flowchart for performing DOE analysis on Rectangular Pocket Machining (RPM) the last process is the results finite element models are a kind of numerical simulation approach that is a natural extension of analytical formulations and is used to generate comprehensive models throughout the manufacturing process [5], [13]. It may offer specific information from the machining process, such as cutting speed, chip generation, stress-strain analysis, and feed rate, which are all dependent on the cutting circumstances. Calibration was done using a finite element model, and validation was done by comparing the experimental findings to the numerical simulation data. The findings show that simulated values and experimental testing match well, and that the results are based on two kinds of tests: calibration and validation. This is due to the fact that the validity of numerical simulation models and analytical formulations can only be proved by experimental data [16]. It is concluded that the finite element model is the true key to reducing manufacturing costs in terms of machining time savings and cutting tool life extension [17].

The DOE methodology is an effective tool for upgrading the level of measurement and assessment. In any design, planning or control problem the designer is faced with many alternatives [5]. It is challenged to develop design approaches that can meet both quality and cost criteria. The way experiments are designed greatly affects the effective use of the experimental resources and the easiness with which the measured results can be analyzed [11].

Table 2: Data parameter material

PARAMETER FOR DRAWING MACHINING PART						
Software : SolidWork						
Finite Element analysis						
No	**Types of material**	**Yield strength (N/m^2)**	**Von mises**	**Displacement**	**Strain (Equivalent)**	**force value (N)**
1	*Aluminium Alloys 1060*	2.76E+07	2.86E+02	4.01E-06	4.03E-09	250
			1.43E+02	2.00E-06	2.06E-09	250
			7.28E-01	1.00E-30	5.48E-11	250
			4.93E+02	2.67E-06	4.62E-09	500
			2.47E+02	1.33E-06	2.32E-09	500
			8.23E-01	1.00E-30	1.12E-11	500
			9.86E+02	5.33E-06	9.24E-09	1000
			4.94E+02	2.67E-06	4.63E-09	1000
			1.65E+00	1.00E-30	2.24E-11	1000

Table 2 shows one of the parameter materials from four material by using SolidWorks before proceding to Minitab software. Minitab provides a quick, effective solution for the level of analysis required in most Six Sigma projects or other statistic data such as Doe analysis[19].

Minitab is a dependable, powerful, and easy-to-use quality control and statistical analysis application that assists you in processing, calculating, analysing, and reporting statistical tasks[18]. It's a complete programme that gives users access to a variety of complex and accurate statistical computation capabilities. It's a useful tool with features that help you optimise your workflow, as well as a full collection of statistics for analysing your data and graphs for presenting your progress. For descriptive and inferential analysis, it provides an excellent user experience. The software is useful for making behavioural pattern judgments based on data analysis, collecting, research, postprocessing, and categorization[19], [20]. It provides a simplified approach to automate massive computations and the development of graphs, and it is the ideal answer for the most difficult business challenges. The application has an interactive interface that takes the user through his analytical tasks and assures the accuracy and reliability of the findings. the table 2.0 is showing the data and parameter upload to as datasheet to Minitab software.

Table 3: List of factors for each DOE analysis

Analysis details / DOE analysis	Number of parameters (Factors)	Factors for each DOE analysis
RPM parameters	Four	1. Yields 2. VonMises. 3. Displacement. 4. Strain.

2.3 Equations

All conceivable circumstances in an experiment are evaluated in the Design of Experiment (DOE) approach in order to discover the key variables [21].Furthermore, since all key aspects (parameters) are considered throughout the DOE analysis, DOE may be utilised as a tool to understand a specific process. As a consequence, DOE will be able to identify the most important criteria for quality improvement.

DOE is also a well-known strategy for preparing large-scale experiments since it can create the necessary number of runs to understand the behaviour of the parameters under investigation. DOE can also reveal the most important techniques for increasing a system's efficiency[21].

There are two frequently utilised DOE techniques (Factorial design and Taguchi method)[4], [5], [12]. However, only the factorial design approach is employed in this study [4] table 4.0 the mathematical model derived from DOE is as follows:

Table 4: The mathematical model derived from DOE

$$Y = \mu + \alpha * A + \beta * B + (\gamma) * A * B$$

(Error! No text of specified style in document..1)

Notation	Y	: Response value
	μ	: Overall mean
	α, β	: Main effects
	A, B	: Factors
	γ	: Interaction effect

3. Results and Discussion

3.1 DOE analysis

The investigation and research discover the optimum material and mechanical design for a specific purpose by using doe analysis and to determine the material and setting mechanism. Performing assessments using computational models and analytic tools saves time and money while also improving design performance [5]. The process may rapidly settle on the best-form design solution across multiple degrees of freedom by combining analytical studies with Configuration process [13].

3.2 Results

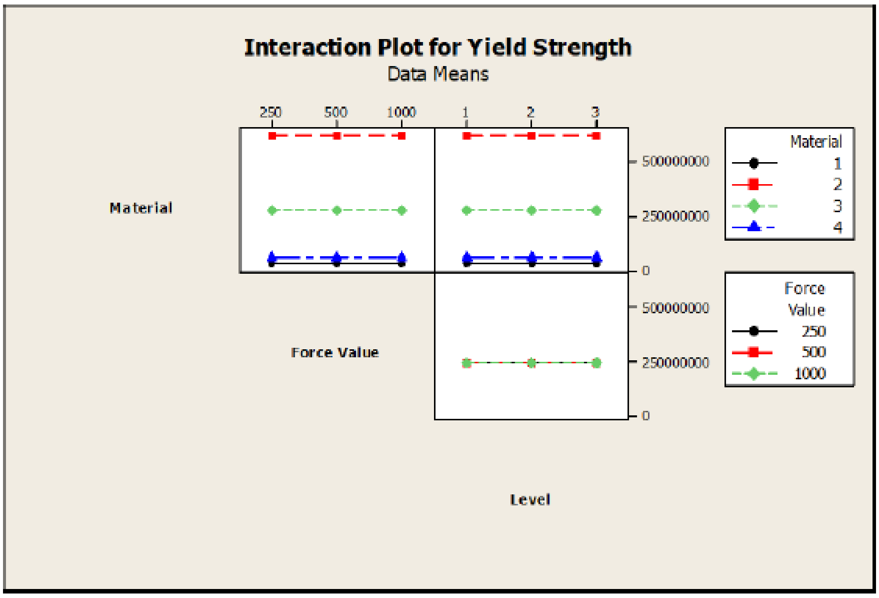

Figure 4: Graph analysis interaction plot for yield strength

The results in Figure 4 is for the Top left (Material vs Force Value), the value of the material is showing the same trend for every force value at ranges 250 to 1000 Newton. But for the yield strength value there is a similarity [9]. The material 1 has the lowest yield strength while the second material testing has the highest value. For the top right we could see the material vs level, the material shows the same trend at every level which is the value of yield strength is similar. From the bottom there is force value vs level for all force values have equal yield strength at all three levels.

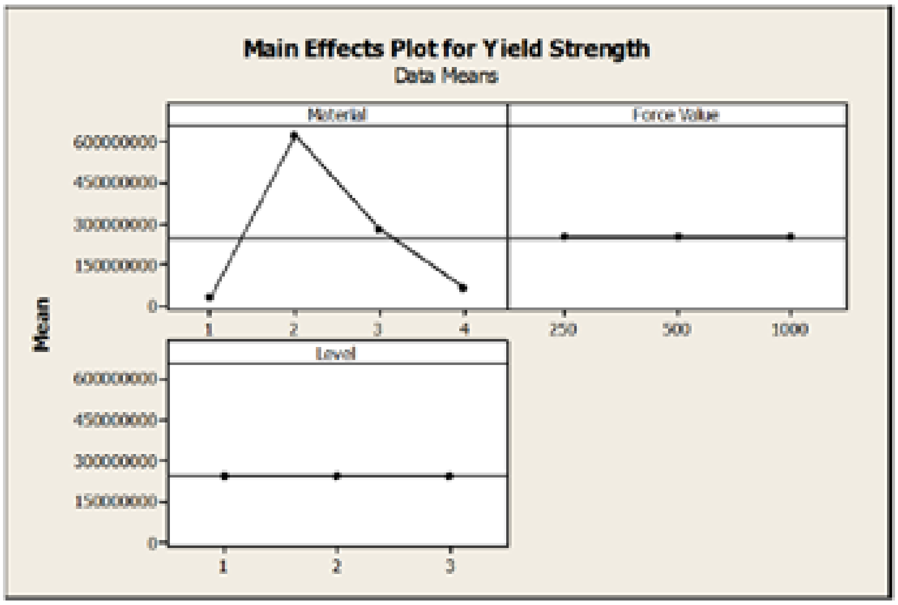

Figure 5: Graph analysis main effect plot for yield strength

The Figure 5 above shows the main effect plot for yield strength, there is Material 2 has the highest yield strength value, followed by Material 3, 4 and 1.for the other data analysis there is the yield strength for all force value is equal. But for all levels also has the similar yield strength value.

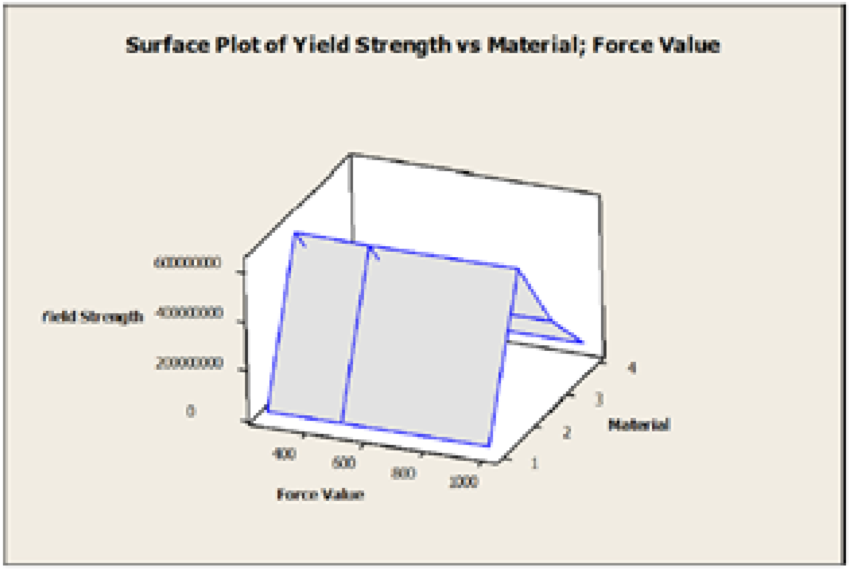

Figure 6: Graph analysis surface plot of yield strength vs material: force value

The Figure shows the Surface plot of Yield strength vs Material and force value. There is material 2 has the highest yield strength and material 2 has the lowest. For the others factor there is for each material, the yield strength is equal for all force values [13]. Because there are so many processes involved in the progress of machining, the doe on product design is can be assessed by data analysis FEA using forces 250 N-1000 N in three stages to get the result of Yield strength, VonMises, displacement, Strain. In terms of design, materials, tooling setup, and machining, software engineering, particularly SolidWorks and Mastercam, will increase productivity. Accompanying discussions that further explain observations of the results are usually placed immediately below the results paragraph.

4. Conclusion

In this study, the investigation of Rectangular Pocket Machining simulation using Design of Experiment is potential to optimize the significant parameter about the design and process by using Doe by Minitab. The Finite Element Method with Design of Experiments techniques can be used in order to contribute towards the optimization of RPM model processes. Further investigation is needed to explore more parameters and operating conditions to develop a general model for more material types. It is recommended to experimentally perform the significant process that combines the optimal set of parameters and monitor its output quality. The study and research the investigation of rectangular pocket machining simulation using design of experiments (doe). This is a widely used concept in a variety of manufacturing industries, particularly in the automotive industry and part of component in machine or electrical appliance, especially the aspect in material and FEA analysis with Design of experiment. The cutting speed and feed rate were chosen as the study's cutting parameters will be analysis for producing product in material selection for testing by Mastercam and SolidWorks on yields strength, VonMises, Displacement, Strain and forces. The analysis demonstrates that the system's efficiency can be determined by data of material run by structure and forces of the material design by using Minitab, which aids in the resolution of potential issues and the product design effected in design process before the machining process begin. It is very important to process, designing, material analysis with FEA element and doe, the synchronize of the setting element is the key for the successful finishing of the quality of the product and it highly could save the cost regarding design and develop the new product in manufacturing process.

Acknowledgement

The author would like to thank Faculty of Engineering Technology, Universiti Tun Hussein Onn Malaysia (UTHM) for its support.

References

[1] B. A. Lukas, “Reducing Cycle Time in the New Product Development Process : A Best Practices by,” no. January, 2014.

[2] Y. Cai, Z. Liu, Z. Shi, Q. Song, and Y. Wan, “Optimization of machining parameters for micro-machining nozzle based on characteristics of surface roughness,” *Int. J. Adv. Manuf. Technol.*, vol. 80, no. 5–8, pp. 1403–1410, 2015, doi: 10.1007/s00170-015-7115-1.

[3] E. Al-momani and I. Rawabdeh, “An Application of Finite Element Method and Design of Experiments in the Optimization of Sheet Metal Blanking Process,” *Jordan J. Mech. Ind. Eng.*, vol. 2, no. 1, pp. 53–63, 2008.

[4] H. Hernadewita, I. Rochmad, H. Hendra, H. Hermiyetti, and E. N. S. Yuliani, “An analysis of implementation of Taguchi method to improve production of pulp on hydrapulper milling,” *Int. J. Prod. Manag. Eng.*, vol. 7, no. 2, p. 125, 2019, doi: 10.4995/ijpme.2019.10163.

[5] Z. Taha *et al.*, “Analysis Guide for Chand...Resolution Spectroscopy.pdf,” *Ger. Res.*, vol. 62, no. 2, p. 144, 2019, doi: 10.1016/j.procir.2014.03.056.

[6] K. Szwajka and T. Trzepieciński, “Effect of tool material on tool wear and delamination

during machining of particleboard," *J. Wood Sci.*, vol. 62, no. 4, pp. 305–315, 2016, doi: 10.1007/s10086-016-1555-6.

[7] A. Ozcan, E. Rivière-Lorphèvre, H. N. Huynh, F. Ducobu, O. Verlinden, and E. Filippi, "Modelling of Pocket Milling Operation Considering Cutting Forces and CNC Control Inputs," *Procedia CIRP*, vol. 58, no. December, pp. 239–244, 2017, doi: 10.1016/j.procir.2017.03.187.

[8] J. C. Najmon, S. Raeisi, and A. Tovar, *Review of additive manufacturing technologies and applications in the aerospace industry*. Elsevier Inc., 2019.

[9] V. Jagota, A. P. S. Sethi, and K. Kumar, "Finite element method: An overview," *Walailak J. Sci. Technol.*, vol. 10, no. 1, pp. 1–8, 2013, doi: 10.2004/wjst.v10i1.499.

[10] I. D. Erhunmwun and U. B. Ikponmwosa, "Review on finite element method," *J. Appl. Sci. Environ. Manag.*, vol. 21, no. 5, p. 999, 2017, doi: 10.4314/jasem.v21i5.30.

[11] M. Barad, "Design of Experiments (DOE)—A Valuable Multi-Purpose Methodology," *Appl. Math.*, vol. 05, no. 14, pp. 2120–2129, 2014, doi: 10.4236/am.2014.514206.

[12] M. Nurhaniza, M. K. A. M. Ariffin, F. Mustapha, and B. T. H. T. Baharudin, "Analyzing the Effect of Machining Parameters Setting to the Surface Roughness during End Milling of CFRP-Aluminium Composite Laminates," *Int. J. Manuf. Eng.*, vol. 2016, pp. 1–9, 2016, doi: 10.1155/2016/4680380.

[13] A. Afkhamifar, D. Antonelli, and P. Chiabert, "Variational Analysis for CNC Milling Process," *Procedia CIRP*, vol. 43, pp. 118–123, 2016, doi: 10.1016/j.procir.2016.02.164.

[14] W. Li, Y. B. Guo, M. E. Barkey, and J. B. Jordon, "Effect tool wear during end milling on the surface integrity and fatigue life of inconel 718," *Procedia CIRP*, vol. 14, pp. 546–551, 2014, doi: 10.1016/j.procir.2014.03.056.

[15] S. Verma and P. S. Rao, "Study on Mechanical Behavior of Aluminum Alloy 6061 Based Composites a Review," *IOSR J. Mech. Civ. Eng. e-ISSN*, vol. 15, no. 4, pp. 16–20, 2018, doi: 10.9790/1684-1504031620.

[16] S. Cao and J. Guan, "Research on CNC Machining Process and Programming Technology of Complex Parts Based on Power MILL," vol. 83, no. Mcei, pp. 309–312, 2018, doi: 10.2991/mcei-18.2018.62.

[17] M. K. Khashan, H. H. Khaleel, and A. H. Meteab, "Numerical study and analysis of ship propeller," *J. Mech. Eng. Res. Dev.*, vol. 40, no. 4, pp. 572–578, 2017, doi: 10.7508/jmerd.2017.04.006.

[18] S. Rasmussen, "An Introduction to Statistics with Data Analysis.," *Biometrics*, vol. 49, no. 3, p. 959, 1993, doi: 10.2307/2532228.

[19] D. Booth, "Pervaiz Alam , Kent State University."

[20] R. S. Pokarne, "Minitab case study ford," no. March, 2021, doi: 10.13140/RG.2.2.17031.73121.

[21] M. Shouran, F. Anayi, M. Packianather, and M. Habil, "Different Fuzzy Control Configurations Tuned by the Bees Algorithm for LFC of Two-Area Power System," *Energies*, vol. 15, no. 2, p. 657, 2022, doi: 10.3390/en15020657.