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# Learning Experience of Machining Carbon Fibre CFRP AL2024 Using Design of Experiment (DoE) Approach

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**Abstract:** *The rapid technological changes required that Technical & Vocational Education Training, TVET's trainees continuously update their knowledge and skills especially in the machining sectors. Traditionally, trainees are only trained to be a good machinist through theory and practical sessions however; they do not equipped with the mastery of underlying knowledge and scientific principles. Present teaching approach of machining cannot provide solid solution on these issues. This paper describes the implementation of Design of Experiment (DoE) methodology on machining composite materials via design expert software. The main objective of this paper is to share learning experience of machining CFRP Al2024 and propose the generic approach of implementing DoE in machining as an embedded technique for trainees to re-skilling and continuing professional development. It was revealed that the generic approach established the relation between the cutting parameters and the response variable to perform analysis and optimization correctly.*

**Keywords:** learning experience, design of experiment, TVET

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## 1. Introduction

Transformation of TVET is designed not only to produce highly trained workforce to meet demands in the job market but also holistic manpower who are capable of facing new challenges. The development of technical and cognitive element in TVET is crucial for individual's self-actualization in shaping holistic human capital. However, the enrichment of the technical expects is more crucial. One of this crucial aspects is the quality of TVET curriculum, which needs to be upgraded and harmonized to align with the industry requirements as well as to build capabilities (Rasul et al., 2015).

Design of Experiment (DoE) methodology is one of the approaches to be embedded in enhancing TVET curriculum. DoE is a systematic approach to understand the process and product parameters that affect the response variables. It is defined as a series of tests in which purposeful changes are made to input factors so that the causes for significant changes in the output responses can be identified. It is a mathematical tool that generates, summarizes and evaluates to ensure their feasibility. By doing this, time spent in conducting experiments can be minimized and the quality of experiments can be controlled. In short, DoE approaches is able to minimize trails and save a lot of time and cost (Anderson, 1997). There is a lot of DoE software available in the market such as Design Experts, Mini Tab and statgraphics. DoE is an integrated software which is a set of mathematical and statistical techniques useful for modelling and analyzing of complex process optimization(Gonzales, 1998).There are few types of DoE, i.e., full factorial designs, fractional factorial designs, Placket Burman designs, response surface designs, Taguchi designs and mixture designs.

Machinists can no longer afford to experiment in a trial-and-error manner. DoE makes our job easier. In any machining training or process beside to obtain accurate dimensions, achieving preferable surface quality and maximized metal removal are also important. Any machining process involves many process parameters which directly or indirectly influence the surface roughness. The surface roughness depends on many factors such as cutting parameters, namely spindle speed, feed rate and depth of cut. A precise of these optimum parameters would facilitate in reducing machining costs and improving product quality.

## 2. Literature Review

Extensive studies have been conducted in the past to optimize the cutting parameters in machining process to have the best surface roughness (Mohamed et al., 2016). Mohamed et al., (2015) utilized DoE, two level full factorial design to investigate machining parameters optimization for trimming operation of Carbon-Fibre Reinforced Plastic laminated with Aluminum grade 2024 (CFRP/Al2024) using milling machine. They analyzed the influence factors and the interaction between these cutting parameters and determined the optimum machining parameters for minimizing surface roughness. Surface roughness of CFRP is found to be 1.778 µm and Al2024 is found to be 0.983 µm at the setting of spindle speed 1860 rpm, feed rate 620 mm/min and depth of cut 0.12 mm respectively.

The application of Taguchi methods in optimizing the cutting parameters (depth of cut, cutting speed and feed rate) of end-milling process under dry condition was studied by(Pang et al., 2014). The surface roughness of the machined composite and the cutting forced was measured. Taguchi method was employed to determine the best combination of cutting parameters could provide the optimal machining response conditions, i.e. the lowest surface roughness and the lowest cutting force values. Benyounis & Olabi (2008) stated that Taguchi method was one of the powerful optimization techniques to improve product quality and reliability at low cost.

Based on the research done by (Sait et al., 2009; Benyounis & Olabi, 2008; Tsao & Hocheng, 2004), computational time done by Taguchi design method was at the medium as compared to Response Surface Methodology (RSM) and Factorial design. Rajmohan et al. (2012), performed on the investigation on optimal design of cutting parameters for drilling hybrid matrix composite. The effect of input parameters namely, spindle speed, feed rate and weight percentage on the thrust force and surface roughness was studied in this experiment. They applied RSM and Central Composite Design (CCD) for modelling, optimization and analysis. This investigation proved that the proposed approach could be useful to improve the performance of the process.

The optimization of turning parameters on surface roughness of glass fibre reinforced plastic was carried out by Palanikumar et al. (2004). By using DoE and analysis of variance (ANOVA), the authors concluded that the technique was so convenient and economical to predict optimal cutting parameters. Desai & Rana (2012) studied the optimum drilling parameters, spindle speed and feed rate on CFRP laminates to get optimum cutting conditions. DoE methodology by full factorial design was used in multiple objective optimizations (using software, Mini Tab 16) to find the optimum cutting conditions for defect free drilling.

Haddad et al., (2013) conducted high speed trimming of a multidirectional CFRP using unused and used burrs tools to investigate the influence of the machining parameters (feed speed, cutting speed and cutting distance) on the cutting forces, machining temperature, and the machined surface quality. The experiment was conducted using full factorial design and the ANOVA was used to analyze the experimental results. They found that the machining parameters had a significant influence on the variation of the machined surface quality and the cutting forces.

From the above literature reviews, the utilization of design of experiment (DoE) methodology is very useful in optimization of machining. This research attempts to implement DoE methodology in TVET which focuses on machining composite materials. The use of design expert software to assist the systematic design matrix, analysis and optimization were employed. The main objective of this paper is to propose the generic approach of implementing DoE in machining in order to enhance the knowledge and skills of TVET trainees.

## 3. Methodology

The material used for this experiment is Carbon Fibre-Reinforced Plastic (CFRP) laminated with Aluminum grade 2024 (Al2024). The lay-up sequence of the unidirectional CFRP prepreg (90/-45/0/45/90/-45/0/45) was adopted to get a symmetric stacking (Zitoune et al., 2010). The trimming process was done via Mori Seiki NV4000 DCG CNC milling machine under dry cutting conditions using KENNAMETAL KCN05 10mm cutting tool. Down milling method was used to produce the optimal surface roughness.

Each trimming process was conducted randomly to avoid systematic error. Two level full factorial design was chosen in this experiment. The machining parameter used for trimming process is shown in table 1.Spindle speed, feed rate and depth of cut were the control factors considered in the experiment. The surface roughness was measured using Mitutoyo SJ-301. Figure 1 shows the experiment set-up comprising of marking, fixing and alignment, trimming and measuring surface roughness of the specimens.

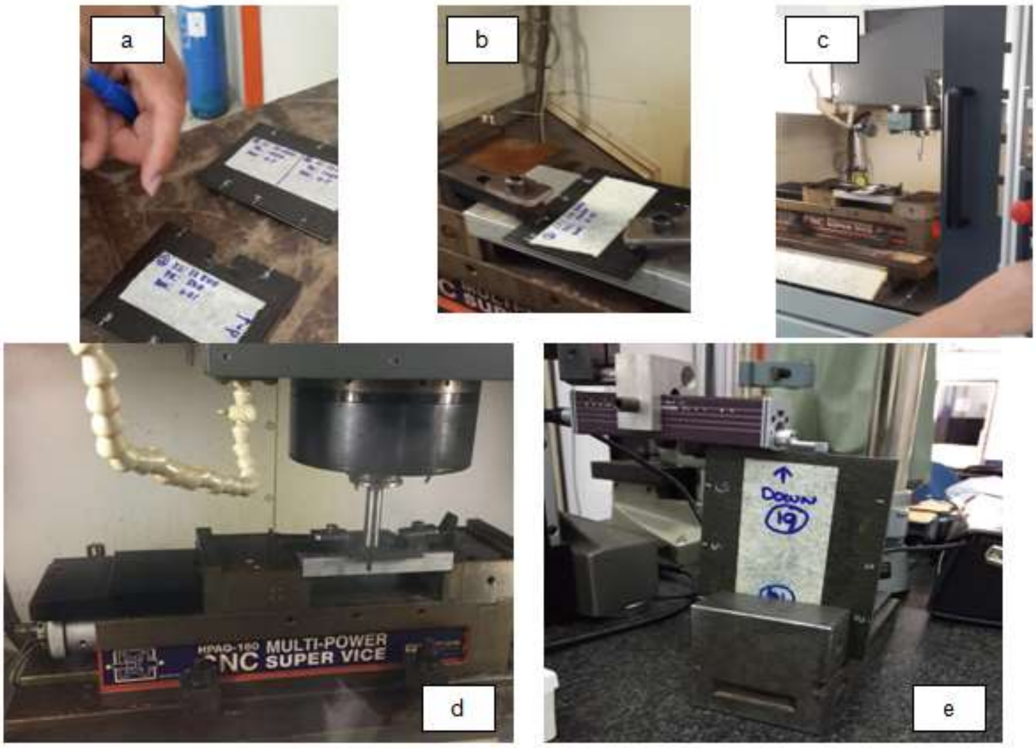


**Figure 1: Experimental set-up, (a) marking of CFRP/Al2024, (b) fixing, (c) aligning,(d) trimming, (e) measuring of surface roughness**

**Table 1: Machining Parameters for Trimming**

| Spindle speed (rpm) | Feed rate (mm/min) | Depth of cut (mm) |
|---|---|---|
| 10000 | 500 | 0.01 |
| 13500 | 1000 | 0.50 |

## 4. Discussion and Conclusion

The replication of the current design was recommended by the software with an addition of three centre points. Thus the total number of 19 experiments was conducted ( $2^3$ = 8 experiments + 8 experiments + 3 centre points). Table 2 shows the results of surface roughness of CFRP and Al2024.

**Table 2: Surface roughness results of CFRP and AL2024**

| **Expt. No.** | **Spindle Speed (rpm)** | **Feed Rate (mm/min)** | **Depth of Cut (mm)** | **Surface Roughness (μm)** | |
|---|---|---|---|---|---|
| | | | | **CFRP** | **Al2024** |
| 1 | 13500 | 1000 | 0.5 | 0.56 | 0.34 |
| 2 | 10000 | 500 | 0.5 | 0.66 | 0.35 |
| 3 | 10000 | 1000 | 0.5 | 0.73 | 0.54 |
| 4 | 11750 | 750 | 0.25 | 0.49 | 0.22 |
| 5 | 13500 | 500 | 0.01 | 0.45 | 0.34 |
| 6 | 10000 | 1000 | 0.01 | 1.04 | 0.21 |
| 7 | 13500 | 500 | 0.5 | 0.42 | 0.73 |
| 8 | 10000 | 500 | 0.01 | 0.44 | 0.28 |
| 9 | 11750 | 750 | 0.25 | 0.49 | 0.22 |
| 10 | 13500 | 1000 | 0.01 | 0.89 | 2.02 |
| 11 | 11750 | 750 | 0.25 | 0.60 | 0.20 |
| 12 | 11750 | 1000 | 0.25 | 1.03 | 0.55 |

| | | | | | |
|---|---|---|---|---|---|
| 13 | 11750 | 750 | 0.25 | 0.75 | 0.37 |
| 14 | 11750 | 750 | 0.5 | 0.54 | 0.26 |
| 15 | 11750 | 500 | 0.25 | 0.50 | 0.42 |
| 16 | 11750 | 750 | 0.01 | 0.43 | 0.47 |
| 17 | 13500 | 750 | 0.25 | 0.53 | 0.80 |
| 18 | 11750 | 750 | 0.25 | 0.74 | 0.36 |
| 19 | 10000 | 750 | 0.25 | 0.82 | 0.74 |

The analysis of variance (ANOVA) for surface roughness of CFRP and Al2014 was conducted separately. Statistically, the model F-value of 6.29 implies that the model is significant. P-value is less than 0.0500, which indicates that the model is significant. In this case A, B and BC are significant model terms. The analysis shows that spindle speed and feed rate have a significant effect on surface roughness of CFRP. The depth of cut has no significant effect but there is a significant interaction effect between feed rate and depth of cut as shown in table 3.

**Table 3: ANOVA for roughness result of CFRP**

| Source of Variance | Sum of Square (SS) | Degree of Freedom (d.o.f) | Mean Square = SS/d.o.f | F Value | P Value | Remarks |
|---|---|---|---|---|---|---|
| Model | 0.063 | 9 | 0.070 | 6.29 | 0.0182 | Significant |
| A-Spindle speed | 0.091 | 1 | 0.091 | 8.19 | 0.0287 | Significant |
| B-Feed rate | 0.25 | 1 | 0.25 | 22.72 | 0.0031 | Significant |
| C-Depth of cut | 0.055 | 1 | 0.055 | 4.99 | 0.0669 | |
| AB | 1.513E-003 | 1 | 1.513E-003 | 0.14 | 0.7243 | |
| AC | 0.017 | 1 | 0.017 | 1.49 | 0.7243 | |
| BC | 0.11 | 1 | 0.11 | 9.74 | 0.0206 | Significant |
| Residual | 0.066 | 4 | 0.011 | | | |
| Lack of fit | 0.066 | 6 | 0.017 | 497.29 | 0.0020 | Significant |

The analysis of variance (ANOVA) for surface roughness of Al2014 shows that the model F-value of 4.60 implies that the model is significant. P-value less than 0.0500 indicate that the model terms are significant. Thus, C and AB are significant model terms. The surface roughness of Al2024 was influenced by the interaction between spindle speed and feed rate. The depth of cut has significant effect, but spindle speed and feed rate are not significant. The ANOVA for surface roughness of Al2024 is shown in table 4.

**Table 4: ANOVA for roughness result of Al2024**

| Source of Variance | Sum of Square (SS) | Degree of Freedom (d.o.f) | Mean Square = SS/d.o.f | F Value | P Value | Remarks |
|---|---|---|---|---|---|---|
| Model | 0.42 | 9 | 0.046 | 4.60 | 0.0384 | Significant |
| A-Spindle speed | 0.036 | 1 | 0.036 | 3.59 | 0.1068 | |
| B-Feed rate | 0.016 | 1 | 0.016 | 1.60 | 0.2531 | |
| C-Depth of cut | 0.13 | 1 | 0.13 | 12.94 | 0.0114 | Significant |
| AB | 0.061 | 1 | 0.061 | 6.11 | 0.0484 | Significant |
| AC | 3.966E-004 | 1 | 3.966E-004 | 0.040 | 0.8489 | |
| BC | 4.561E-004 | 1 | 4.561E-004 | 0.045 | 0.8382 | Significant |
| Residual | 0.060 | 6 | 0.010 | | | |
| Lack of fit | 0.060 | 4 | 0.015 | 112.32 | 0.0088 | Significant |

Overlay plot in figure 2 shows the graphical overview of the proposed factor settings with yellow shaded area meeting the target responses. The yellow zone represents the zone of optimum responses from 0.4 to 0.6 μm with the setting 0.255 mm depth of cut. The range of spindle speed for a pre-setting surface roughness value should be in between 12300 to 13500 rpm and the feed rate should be approximately between 560 to 780 mm/min.

The validation experiment was conducted at optimum level of recommendation control factors setting to compare the deviation of predicted value from actual/measured value. In most engineering cases, if the percentage error or difference between predicted and measured value less than 10%, the developed model is accepted. Table 5 shows the deviation of predicted value from the measured value is 3.11% for CFRP and 3.36% for Al2024.

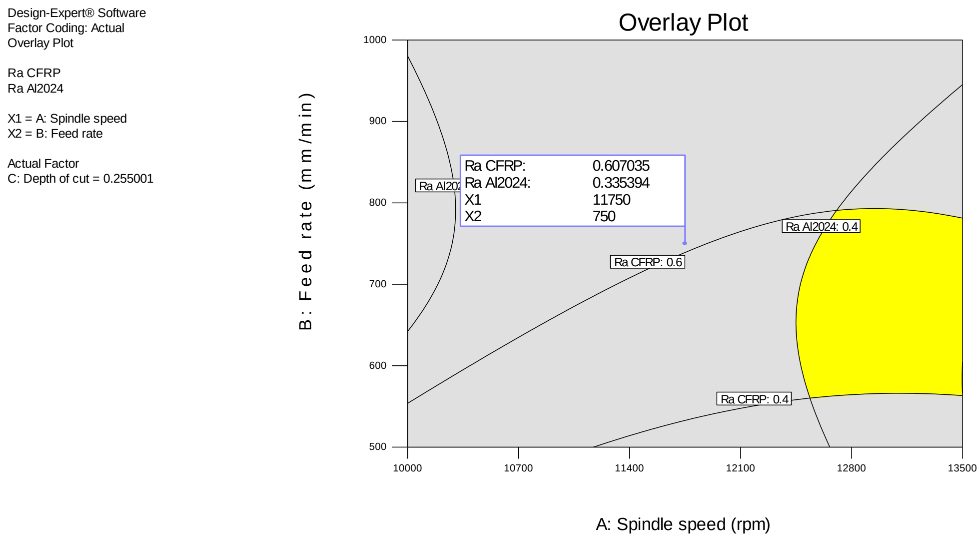


**Figure 2: Overlay plot of CFRP/Al2024**

**Table 5: Validation experiment results on surface roughness of CFRP and Al2014**

| Run No. | Spindle Speed (rpm) | Feed Rate (mm/min) | Depth of Cut (mm) | Surface Roughness (μm) | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | CFRP | | | Al2024 | | |
| | | | | Actual | Measured | % Error | Actual | Measured | % Error |
| 1 | 11750 | 750 | 0.255 | 0.594 | 0.607 | 2.20 | 0.320 | 0.355 | 4.69 |
| 2 | 11750 | 754 | 0.257 | 0.586 | 0.610 | 4.03 | 0.328 | 0.335 | 2.04 |
| | | | | Average % Error | | 3.11 | Average % Error | | 3.36 |

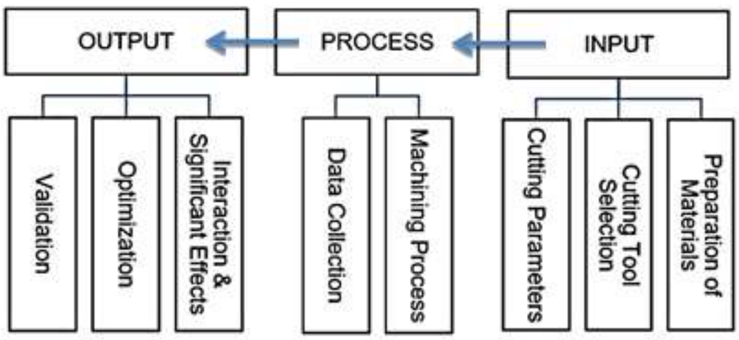


**Figure 3: A model of DoE in TVET implementation**

The implementation of design of experiment methodology using two level full factorial designs was conducted in machining of composite materials for optimizing of cutting parameters. The DoE methodology applied in this study showed the systematic way of setting optimum cutting parameters and the analyzing the significant interactions of the control factors (spindle speed, feed rate and depth of cut) to produce surface quality of CFRP/AL2024. In conclusion, the implementation of DoE in TVET as part of an enhancement program can be divided into three elements as shown in figure 3. The input parameters can be considered as a primary parameter in ensuring the machining process and data collection can be performed. The process ends up with validation and optimization of finding the best solution of the controlled variables to meet the specific objectives. This methodology can aid trainees to acquire knowledge and skills in machining more efficiently and enable them to perform analysis and optimization for cutting parameters correctly.

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