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Analysis Of Cutting Accuracy Using CNC Router Machine Based on Workpiece Thickness, Spindle Speed and Cutting Form

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Abstract: The utilization of CNC Router machines has gained significant traction among practitioners in the field of creative arts due to their ability to expedite the production process of various artistic and functional products. However, despite the widespread adoption of this technology, the issue of dimensional accuracy and precision in the final output remains largely underexplored within the creative industry. This study aims to critically analyze the dimensional accuracy of products fabricated using a CNC router machine. In this research, a CNC router with a working bed dimension of 8 feet by 4 feet was employed. The research specifically examined the correlation between spindle speed, workpiece thickness, and the accuracy of geometric cuts, namely square and circular shapes. Accuracy was evaluated in terms of dimensional deviations along both the X and Y axes. The findings reveal notable discrepancies in measurement, particularly along the Y-axis, while the X-axis exhibited relatively minor deviations. At a spindle speed of 3000 revolutions per minute (rpm), the maximum dimensional deviation recorded was 0.1 mm along the X-axis and -0.3 mm along the Y-axis. When operating at 2500 rpm, the maximum deviation increased to 0.2 mm on the X-axis and 0.4 mm on the Y-axis. At a lower spindle speed of 2000 rpm, deviations remained consistent at 0.1 mm on the X-axis and 0.4 mm on the Y-axis. In contrast, circular cuts demonstrated a more uniform pattern of dimensional consistency, with minimal deviation observed across various spindle speeds. These results underscore the significance of optimizing machining parameters, particularly spindle speed to enhance cutting precision, especially along the Y-axis. This study contributes valuable insights into the precision engineering aspects of CNC Router applications and emphasizes the need for meticulous parameter calibration in creative manufacturing processes.

Keywords: CNC machine, spindle speed, workpiece thickness, cutting form, measurement

1. Introduction

Computer Numerical Control (CNC) are increasingly being used in the creative art industry in Kelantan. These developments have contributed to the transformation in the crafts, carpentry and manufacturing sectors The CNC Router machine is getting a place among creative art makers. This machine allows 3D wood carvings, signage and home decorations produced quickly and has a consistency in product quality In addition, the machine also allows local entrepreneurs to produce products with complex and unique designs. This indirectly increases the competitiveness of the product. The ability of the CNC Router machine to produce this digital traditional engraving has assisted in the preservation and dissemination of Kelantan heritage art.

The increase in demand for CNC Router machines has given birth to several local machine manufacturers. The manufacturer of this machine has designed this CNC Router machine according to its own creativity. The components

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used in the production of this machine also depend on the components imported from China. Although there are various sizes and shapes of machines produced, studies on the accuracy of cutting using CNC Router machines are not carried out. Most machine users cannot evaluate the accuracy of the cuts and mostly only depend on graphic drawings before the cuts are made. Motor Stepper and Digital Signal Processor, (DSP) Model A11 which is a kind of microprocessor used to control the motor stepper in the automation system or machine. Stepper Motor is an electric motor that moves in step, ideal for accurate movement. Meanwhile, DSP A11 is an electronic controller used to analyze signals and give instruction to motors based on specific programs.

This study aims to evaluate the influence of various cutting parameters, including workpiece thickness, spindle speed, and cutting form, on the accuracy of CNC Router machining. It also seeks to determine the geometrical tolerance of the cutting results based on different cutting sizes. The research focuses on a locally produced CNC machine router measuring 8 feet in length and 4 feet in width, driven by a stepper motor and controlled using DSP A11. The significance of this study lies in providing technical guidance for assessing the accuracy of cutting square and round shapes using a CNC Router machine. The findings are expected to serve as a valuable reference for both the improvement and innovation of CNC Router machines, contributing to enhanced performance and reliability in the manufacturing process.

1.1 Problem statement

Despite the growing use of CNC router machines in Malaysia's creative arts and small-scale manufacturing industries, there is a lack of systematic study on the cutting accuracy and dimensional precision of locally produced CNC routers. Many users rely solely on design software outputs without understanding how machining parameters, such as spindle speed, workpiece thickness, and cutting form affect actual cutting results. Variations in these parameters can lead to dimensional deviations, vibration, and inconsistent product quality, particularly along different machine axes. Therefore, this study seeks to investigate how these factors influence cutting accuracy to provide technical insight and performance evaluation for locally developed CNC router machines, enabling better calibration, improved design, and more reliable outcomes in creative manufacturing applications.

1.2 Research Objective

The primary objective of this research is to systematically evaluate the influence of machining parameters, specifically spindle speed, workpiece thickness, and cutting form on the dimensional accuracy and geometrical precision of products fabricated using a locally developed CNC router machine. Through controlled experimental analysis, the study aims to identify the extent to which each parameter contributes to deviations along the X and Y axes, thereby establishing the correlation between process variables and cutting performance. Furthermore, this research seeks to generate empirical data that can serve as a technical benchmark for improving the design, calibration, and operational optimization of CNC router machines produced by local manufacturers. Ultimately, the objective is to enhance the precision, consistency, and reliability of CNC machining processes within the creative and manufacturing industries, thereby contributing to the advancement of local technological capability and sustainable innovation in digital fabrication.

1.3 Significance of the Study

The significance of this research lies in its contribution to advancing the precision and performance understanding of locally developed CNC router machines, particularly within Malaysia's creative and manufacturing sectors. By systematically analyzing the effects of spindle speed, workpiece thickness, and cutting form on dimensional accuracy, this study provides empirical insights that bridge the gap between theoretical machining principles and real world industrial practices. Such knowledge is vital for machine designers, operators, and educators seeking to enhance the reliability, consistency, and quality of CNC-based production. The findings not only strengthen the scientific foundation of local CNC technology but also establish technical benchmarks for performance evaluation, calibration, and optimization in future machine design and application.

Furthermore, the research carries broader socio-economic and technological implications. By improving the accuracy and competitiveness of locally manufactured CNC routers, the study supports the growth of small and medium-sized enterprises (SMEs) engaged in digital fabrication, creative craftsmanship, and product innovation. It promotes self-reliance in technological capability, reduces dependence on imported systems, and aligns with Malaysia's TVET and Industry 4.0 agendas toward sustainable industrial modernization. Ultimately, the study contributes to national efforts in cultivating high-value manufacturing skills, enhancing productivity, and fostering innovation ecosystems that integrate engineering precision with creative cultural expression.

2. Methodology

Quantitative experiments and experimental research methods were used in this study. Machining parameters such as spindle speed, workpiece thickness and rectangular and round cutting forms have been controlled and systematically changed to evaluate its effects on the accuracy of the cutting results. Tool bit with the size of 3.175 mm was selected based on the experience and recommendations of the machine operator. The 2 mm tool tip often breaks when cutting 5 mm and 10 mm thick PVC CLC Foam Board, while the 4 mm tool tip takes up a lot of space during the cutting process.

2.1 Study of Spindle Speed Relationship

This study was conducted by changing the speed of spindle from 2000 rpm to 3000 rpm. Speeds below 2000 rpm often lead to poor surface finish and material tearing, while speeds above 3000 rpm may cause excessive heat generation, tool wear, and vibration especially when using lightweight CNC routers or non-industrial spindles. Therefore, 2000 to 3000 rpm provides a safe, stable region where cutting performance can be compared reliably. Before the cuts are made, the fixed parameters are shown in Table 1. The outcome of the cutting is measured based on the length and width readings taken as shown in Table 2. The size of the length represents the Y axis while the width represents the X axis.

Table 1: Fixed parameters for the study on the relationship between spindle speed

Size of tool bit	**3.175**	**mm**
Workpiece	PVC CLC Foam Board	
Thickness of the workpiece	10	mm
Measurement of the workpiece (length x width)	50 x 50	mm

2.1.1 Study of the Relationship Between Workpiece Thickness

Table 2: Fixed parameters for the relationship between workpiece thickness

Size of tool bit	**3.175**	**mm**
Workpiece	PVC CLC Foam Board	
The speed of the tool bit	3000	rpm
Measurement of the workpiece (length x width)	50 x 50	mm

Speed and size of the tool bit, the type of workpiece and the cutting size as shown in Table 3. The cuts are done at 2 different thicknesses, the PVC CLC Foam Board with 5 and 10mm. The thicknesses of 5 mm and 10 mm were chosen to represent two practical and commonly used material thickness ranges in CNC cutting applications for PVC CLC foam boards. These values allow a meaningful comparison of machining performance under different depth conditions while keeping other parameters constant. The outcome of the cutting is measured using the vernier caliper and the reading is recorded as shown in Table 2. The length of the axis represents the Y axis while the width represents the X axis.

2.1.2 Study of the Relationship Between Cutting a Square and a Circle

The rectangles and circles are made using fixed parameters as shown in Table 4. The square measures 6 x 6, 10 x 10, 15 x 15, 20 x 20, 25 x 25, 30 x 30, 35 x 35, 40 x 40, 45 x 45 and 50 x 50 mm (length x width) cut and readings of each size are recorded, and 50 mm cut using CNC router machines and reading products are measured using vernier caliper.

Table 3: Fixed parameters for the study on the relationship between cutting shape

Size of tool bit	**3.175**	**mm**
Workpiece	PVC CLC Foam Board	
Thickness of the workpiece	10	mm
Spindle speed	3000	rpm

2.2 Equipment

2.2.1 CNC Router Machine

The machine produced by a local manufacturer, measuring 8 feet long and 4 feet wide as shown in Fig. 1, is used for this study. The X, Y, and Z axis of this machine are driven by a Stepper Motor. For the y -axis movements are controlled using the gear system while the X and Z axes are moved using lead screws. DSP A11 programmer is used as an intermediary medium between the researcher and the machine.

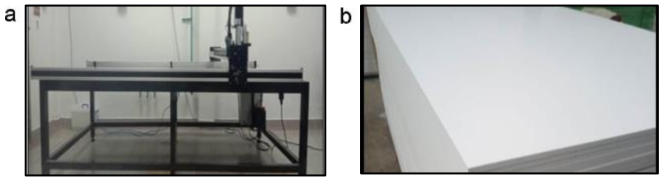

Fig. 1: (a) CNC Router Machine; (b) Workpiece.

2.2.2 Workpiece

PVC CLC consist of 5 mm and 10 mm were used in this study. The selection of this work material is due to its widespread use in the creative arts industry. Its lightweight nature and high durability cause this material to be frequently used.

2.2.3 CAD and CAM software

The Aspire Vectric software has been installed on the computer used to sketch the shape of the product to be produced. Fig. 2 shows the start page of the Aspire software before sketching started. Once the sketching process is completed, the cutting is carried out to ensure that all processes go smoothly.

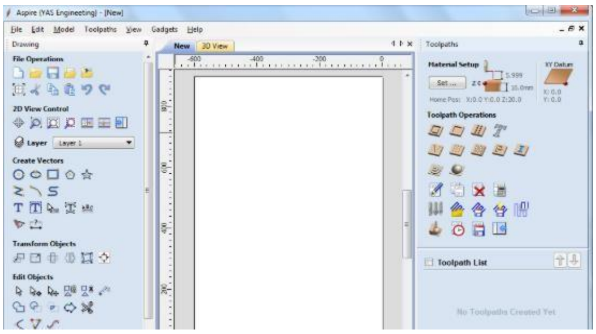

Fig. 2: Aspire Vectric Software

2.2.4 Cutting tools and measurement tools

The endmill cutting tool with a size of 3.175 mm and the Vernier Caliper measuring tool are used during the cutting and measurement processes. Fig. 3 (a) shows the endmill while Fig. 3 (b) shows the vernier caliper used in this study.

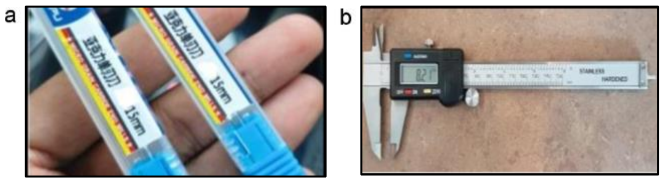

Fig. 3: (a) Endmill; (b) Vernier Caliper.

2.3 Research Procedure

2.3.1 Workpiece Preparation

The workpiece measuring 8 x 4 (Length x Width) feet is placed on the CNC router machine. Fig. 4 shows the shapes of the square and circle cuts that have been sketched and set using Aspire software. Each size is repeated 5 times to ensure the accuracy and validity of the decision. Figure 6 shows the workpiece that has been placed on the CNC machine. This workpiece will be nailed to the WPC Foam Board to reduce vibration during the cutting process.

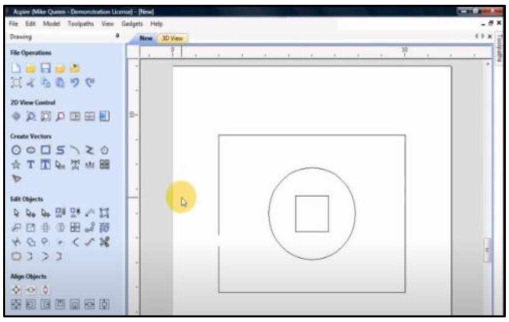

Fig. 4: Square sketches and circles

2.3.2 Machine Setup

The machine is turned on and origin point is set. The programmed cutting shape is transferred to the machine using the DSP A11 programmer. The spindle speed (rpm) and all parameters are set according to the plan, and the cutting process begins. Fig. 5 shows the parameters being set using the DSP A11 programmer.

Fig. 5: DSP A11 programmer

2.3.4 Cutting process

The spindle is operated according to the study plan while monitoring the machine's movement. After cutting, the products are cleaned before measurements are taken. The cutting results are shown in Fig. 6. Measurements are taken using a vernier caliper, and the readings are recorded for analysis. The data is then processed using Excel and graphs to present the findings.

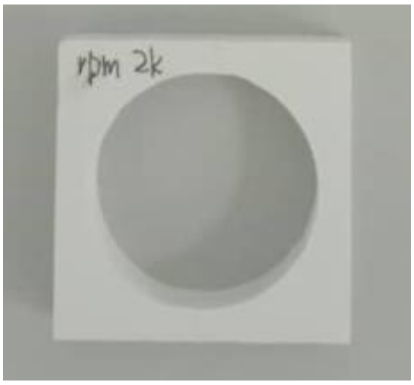

Fig. 6: Cutting results

3. Results

3.1 Study of the Relationship Between Spindle Speed and Cutting Accuracy

The spindle speed of 3000 rpm shows a maximum measurement difference of 0.1 mm on the X-axis and -0.3 mm on the Y-axis. At a speed of 2500 rpm, the maximum difference is 0.2 mm on the X-axis and 0.4 mm on the Y-axis. At a speed of 2000 rpm, the maximum measurement difference is 0.1 mm on the X-axis and 0.4 mm on the Y-axis. Fig. 7 shows the detailed results of the study on the measurement differences and the relationship between spindle speed and cutting accuracy.

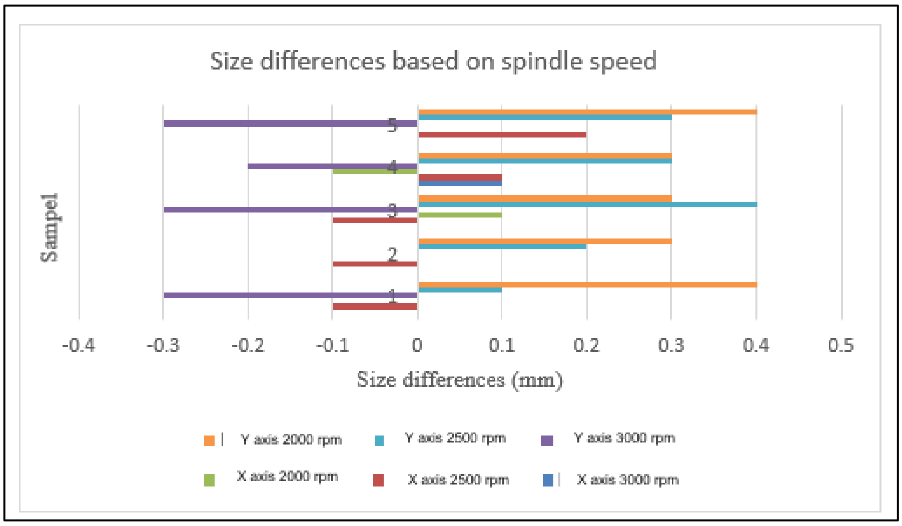

Fig. 7: Size Differences Based on Spindle Speed

3.1.1 Study of the Relationship Between Workpiece Thickness and Cutting Accuracy

Fig. 8 shows the results of the relationship between the thickness of the workpiece and the accuracy of the cutting. A thickness of 5 mm shows a maximum size difference of 0.1 mm on the X-axis and -0.2 mm on the Y-axis. The maximum difference of 0.1 mm on the X-axis and -0.3 mm on the Y-axis is shown on the workpiece with a thickness of 10 mm.

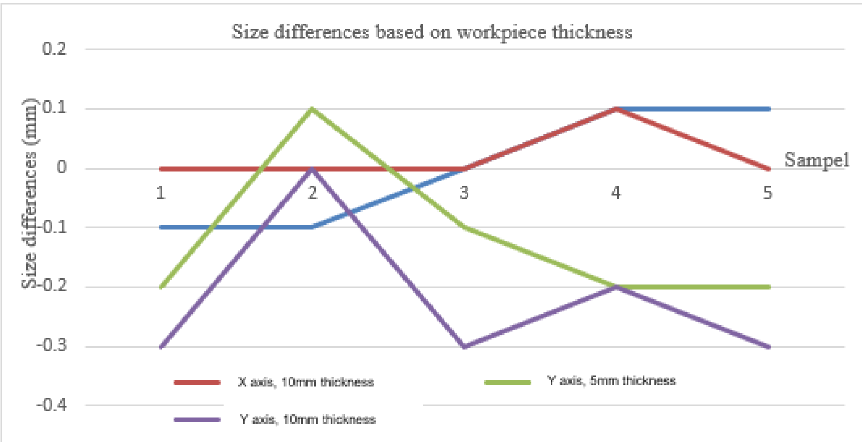

Fig. 8: Size Difference Based on Workpiece Thickness

3.2 Study of the Relationship Between Cutting of Square and Circular Shapes and Cutting Accuracy

The results of the study on the relationship between square cutting and the accuracy of the cutting results are shown in Fig. 9. The maximum difference is 0.5 mm at a 6 mm cut on the Y-axis and -0.2 mm on the X-axis. On the Y-axis, the 10 mm and 20 mm cuts show a maximum difference of 0.3 mm. While other cuts only show a maximum difference of 0.2 mm. On the Y-axis, the maximum difference is at a rate of 0.2 mm.

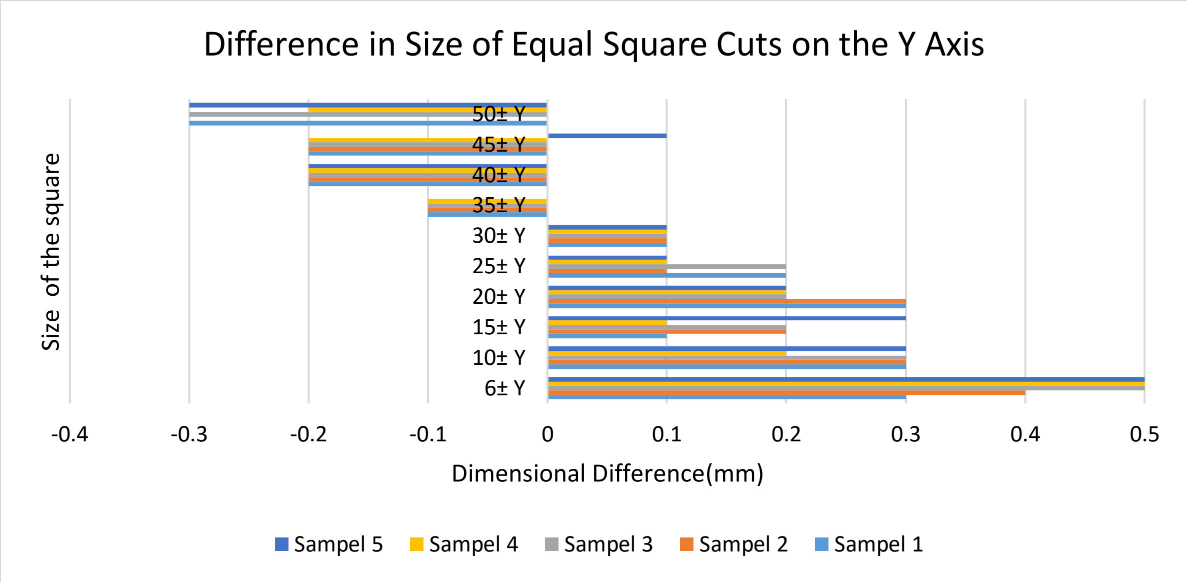

Fig. 9: (a) Dimensional Difference of Square Cutting on the Y-Axi

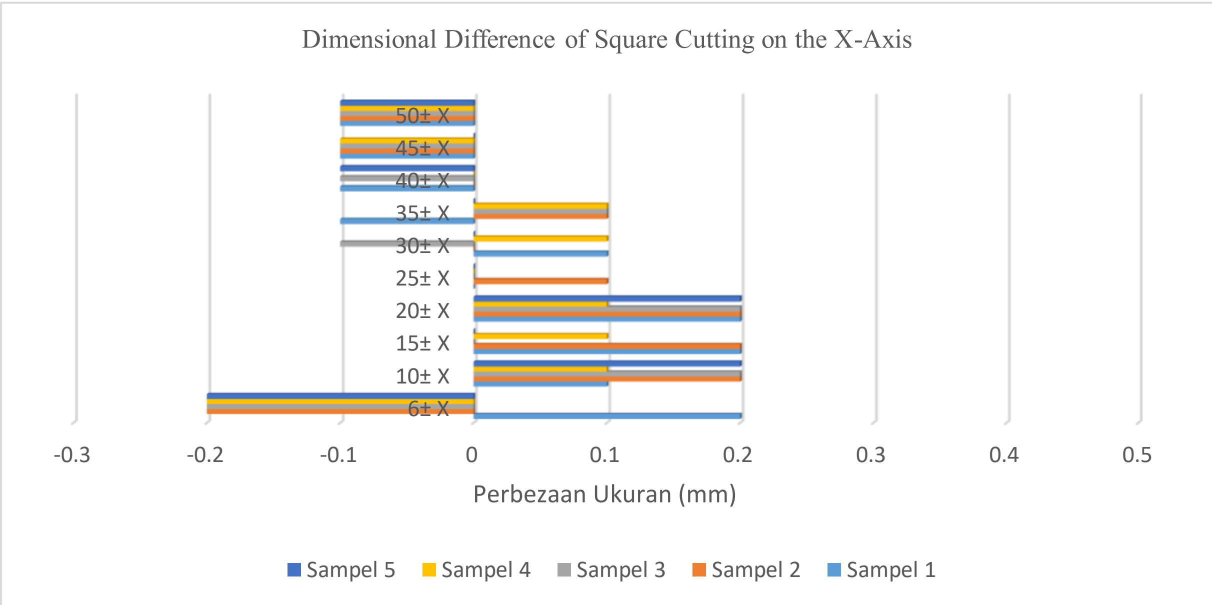

Fig 10: (b) Dimensional Difference of Square Cut on the X-Axis

4. Discussion and Recommendations

Studies on spindle speed with cutting accuracy show a high difference in the Y axis but low differences in the X axis. This difference may be due to vibration during the cutting process. These vibrations are due to the length of the workpiece. In addition, nails that are placed to reduce vibration are also very far from each other. The results also show that the speed of the spindle 3000 rpm has the least difference in size compared to the other. This may be due to lack of vibration during the cutting process. Further studies on spindle speed and workpiece material should be conducted to further understand their relationship.The relationship between the thickness of the workpiece and the accuracy of the cutting shows the thin workpiece reduces the difference in size.

This may be due to the lack of friction between the tool bit and the workpiece during the cutting process. In addition, the tool's heating factor during cutting thicker workpieces also contributes to the outcome. In-depth studies need to be done to determine the relationship of this parameter. The square cutting shows a high difference in small -sized cuts. But the difference is lower as the size increases. This may be due to the size of the large tool bit that can affect the accuracy for small cutting . The circular shape cutting, on the other hand, shows a low and uniform difference.

In conclusion, there are several factors that influence the accuracy of cutting using this local CNC router machine. Among these factors are spindle speed, workpiece thickness, cutting size and size of tool bit used. The same 5 products also indicate differences in accuracy may be due to vibration during the cutting process. These vibrations may vary depending on the position of the workpiece as well as the distance between the cutting area and the nails fixed to the WPC Foam Board. A more in-depth study of nail position on the workpiece needs to be developed to gain a clearer understanding of the relationships.

For future studies, it is recommended to investigate a wider range of spindle speeds and feed rates to better understand their influence on dimensional accuracy and surface finish. Further research should also focus on the effects of different tool bit materials, diameters, and clamping methods to minimize vibration during cutting. In addition, studies involving various workpiece materials and thicknesses, combined with thermal and frictional analysis, would provide deeper insights into cutting performance. Future work may also include simulation or statistical modeling to validate experimental findings and explore the relationship between vibration, tool geometry, and cutting precision in locally developed CNC router machines.

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