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Design, Fabrication, and Performance Evaluation of an Electric Abrasive Wheel Metal Cutting Machine for Small Workshop Applications

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Abstract

Demand for low-cost and energy-efficient metal-cutting machines in small and medium-scale industries is increasing, thereby prompting a need for an indigenous and adapted fabrication machine that can reduce the reliance on costlier foreign machines. Nearly all existing abrasive cutting machines are prohibitively expensive and energy-consuming as well as difficult to maintain in developing countries; however, no prior literature study has coupled engineering design with structural simulation, fabrication, and experimental validation of a suitable application for SMEs. Therefore, this project aimed at the design and fabrication of a low-cost, energy-efficient, and structurally stable electric abrasive-wheel-based metal cutting machine for workshop applications. The method of the study involves conceptualization, modeling using CAD, engineering calculations, selection of materials, Finite Element Analysis (FEA), fabrication and assembly of the machine, experimental analysis of its performance, and subsequent analysis of results obtained. Mild steel, cast iron, and aluminum were selected as the components of the machine based on strengths, vibration resistance, and corrosion resistance. Mild steel rods with diameters of 5, 10, 15, and 20 mm were used to determine the performance of the machine. The parameters studied were cutting time, rise in temperature, energy consumption, and vibration stability, as well as accuracy of the cutting operation. It was experimentally found that a rod of 20 mm in diameter of mild steel can be cut within 6 seconds. Regression analysis indicated that strong linear relation exists between thickness of material and cutting time ($R^2= 0. 0.988$) and between energy consumption and cutting time ($R^2 = 0. 0.997$). The temperature rise study indicated the temperature of the grinding wheel reached a maximum of 57 °C, which is within operating safety limits, and stress distribution analysis from FEA indicated that stresses generated are much less than the yield strength of the materials chosen for designing each part. Also, the study showed that about a 60-75% reduction in fabrication cost was observed compared to imported machines.

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1.0 Introduction

The demands of modern manufacturing and fabrication environments necessitate the development of machines that can execute metal cutting operations with speed, accuracy, and efficiency. Although inexpensive and straightforward to use, conventional manually operated metal cutting tools such as hand hack saws and mechanical saws are unable to adequately meet the demand for speed and high productivity, and the increasing accuracy requirements of metal cutting processes. These devices require manual effort, time-consuming processes, and do not guarantee consistent output, thus restricting their use in industrial and small-scale settings. The requirement for technically sophisticated yet affordable cutting equipment continues to grow, and therefore, an electrically powered grinding wheel metal cutting machine appears to be a timely and necessary engineering invention.

The abrasive wheel, as an abrasive machining tool, can efficiently cut various metallic workpieces. When integrated with a power source, it has the potential to cut a workpiece with high speed, controllable feed, and a relatively maintenance-free system. In this project, an electrically powered abrasive wheel machine that can cut metallic parts quickly, accurately, and efficiently while guaranteeing safety will be developed. The objective of the study is to develop an operator-friendly, cost-effective, and efficient electrically powered abrasive wheel-based metal cutting machine which consistently provides accurate and repeatable cuts across various metals in workshop, training facilities, and light industrial uses.

The mechanical and electrical designs of the machine were carried out, the materials for various components were selected, a stress analysis was performed on the structural components, the components were manufactured and assembled together and evaluated. The operation of the machine has been limited to a semi-automated state; manual-

operated control is provided, and the speed is constant (fixed) without any provision for CNC and automated process control.

Existing technology is either manually operated metal cutting tools that require considerable man-power and time, or high-cost industrial machines that are not economically affordable to the average workshop owner or training institutions. Hence, there is a gap between economically feasible cutting tools and technically superior machines, which this project seeks to address by providing a technically appropriate and viable electric grinding wheel metal cutting machine.

Intelligent manufacturing technology, sensor integration, Artificial Intelligence, and data-driven monitoring systems have significantly impacted grinding and abrasive cutting processes. Early intelligent grinding systems are centered on monitoring the process and condition of the grinding wheel. Varghese et al. (2000) developed a sensor-integrated intelligent grinding wheel for monitoring the ceramic grinding process in real time. They utilized piezoceramic sensors and DSP-based telemetry to measure the forces and acoustic emission during grinding and dressing of the wheel. This study proves that embedded sensing systems are beneficial for process visibility, grinding wheel condition monitoring, and predictive maintenance in precision grinding.

The research for intelligent grinding systems has recently extended the concepts of integrating multiple sensor signals through machine learning techniques. Duan et al. (2024) developed an online grinding wheel wear monitoring system by combining the signals from the acoustic emission, force, and vibration sensors with a support vector machine (SVM). This system achieved monitoring accuracy over 92% with the integration of a multi-sensor fusion approach on wear detection for the grinding wheel. Lopes et al. (2021) proposed a low-cost approach for the fault detection of

grinding processes by utilizing a piezoelectric diaphragm sensor and signal processing techniques. The results showed great correlation with the acoustic emission sensing method, validating the reliability of using a low-cost sensor for optimizing the grinding process.

The concept of intelligent grinding and machining systems has been driven by Industry 4.0 and the smart manufacturing revolution. Kuppuswamy et al. (2021) have carried out a literature review on intelligent grinding systems and have found that there has been a transition in system paradigm from static database systems to dynamic real-time process monitoring and control systems powered by AI and advanced sensors. This article shows the progress towards the fully autonomous intelligent grinding system, but also points out that challenges remain due to total system integration and industrial scaling. Mohamed et al. (2022) had also reviewed tool condition monitoring systems for Industry 4.0 machining operations, and they have emphasized the use of wireless sensors, data acquisition, and Industrial Internet of Things (IoT) for self-adjusting and unmanned machining processes. Numerous researchers have investigated intelligent monitoring architectures and data-driven decision systems for grinding operations. Wang et al. (2024) developed a big data-driven expert system for grinding process optimization using monitored power data and neural-network-based predictive models. This system combines adaptive control and a Pareto optimization strategy to enhance grinding efficiency and energy consumption. Li et al. (2025) have proposed an intelligent grinding process system that is driven by data for sustainable manufacturing. This framework incorporates prediction, optimization and environmental analysis modules and achieved prediction accuracy with R^2 values higher than 0.96 to effectively control the process.

Digital twin and AI, integrated control systems have been continuously studied and developed in modern grinding. Jamshidi and Budak (2024)

developed a digital twin-based approach for predicting grinding process outputs and optimizing grinding parameters with minimal experimental calibration and data. Their model includes grit-level interaction and material deformation to increase productivity and surface quality prediction. Similarly, Park and Tran (2024) proposed a hybrid autonomous control system that integrates digital twin and AI to stabilize the quality of the automotive brake disc during grinding operation.

Advanced sensors and machine learning techniques have also been applied to improve monitoring performance in the grinding process. Pimenov et al. (2025) reviewed advanced sensors utilized for grinding operations, such as vibration analysis, acoustic emission, force sensing, and vision systems, highlighting the growing need for tool wear monitoring and dimensional accuracy. Rajagopal and Prabadevi (2022) provided a literature survey on the utilization of AI and machine learning algorithms in predictive aspects of grinding operation, such as grinding wheel condition, surface roughness, and process stability. Studies on data-driven optimization and process quality control were conducted to improve the outcomes of grinding processes. Kim et al. (2024) established a machine learning and metaheuristic optimization framework to select grinding parameters, which resulted in 77.83% fault rate and 17.64% reduction in cycle time experimentally. Fu et al. (2024) performed a literature survey of pre-control strategies for surface quality improvement in grinding operations using data-driven process analysis and prediction methods. Their study focused on the importance of real-time process monitoring and intelligent control to ensure consistent machining results.

Cutting force, thermal modeling, and vibration suppression methods have been the key areas for the intelligent machining operation. Jiang and Song (2026) reviewed cutting force and thermal modeling strategies for advanced manufacturing,

from analytical methods to the hybrid physics-informed and ML-based models. It has been stated that the utilization of vibration suppression techniques, alongside intelligent control systems to stabilize the grinding operation, is very crucial. Besides, Wan et al. (2026) discussed strategies on the evolution of intelligent cutting tools by means of embedded multi-sensor systems for real-time monitored cutting forces, temperatures, and vibrations, and pointed out that sensor reliability, scalability of systems, and data coupling issues remain major challenges in the field. Pan et al. (2024) proposed a system architecture for an intelligent ultra-precision machining system by combining environmental monitoring, process analysis, and closed-loop adaptive control. Most conventional type abrasive cutting machines will be designed based on general machine design procedures, including designing the shafting, analyzing the power transmission, stresses, safety aspect etc. based on the classic mechanical engineering design books (Budynas & Nisbett, 2020; Khurmi & Gupta, 2019). Besides that, contemporary grinding machines and abrasive cutting systems are often compared to the internationally recognized safety and material standards, e.g., ASTM and ISO standards for the selection of constructional steel, the safety standards of machines, and dimensions.

In spite of the numerous advantages of the intelligent grinding systems discussed, a gap remains to be bridged in the literature. The majority of the available studies involve high-cost intelligent monitoring systems, digital twins, machine learning optimization, and industrial automation, which are applicable to the advanced manufacturing sector only. Few or none of the work integrates engineering design calculation, structural analysis, fabrication, thermal and energy assessment along with experimental evaluation to develop an intelligent and low-cost system for the Small and Medium-sized Enterprise (SME) workshop. Further, many commercial grinding and abrasive

cutting machines are expensive to acquire and difficult to maintain, especially in a developing country, where most of the components are manufactured elsewhere using sophisticated technology.

Hence, the present study fills this gap by integrating engineering design, Finite Element Analysis (FEA), fabrication, and experimental performance verification to develop an inexpensive electric grinding wheel metal cutting machine suitable for educational institutions, vocational centres, and small-scale fabrication workshops. Therefore, the specific objectives of this research work are to:

- i. design and fabricate a novel electric-operated grinding wheel metal cutting machine, applying standard engineering design principles and common locally sourced materials.
- ii. apply engineering calculations and Finite Element Analysis (FEA) to determine structural integrity, power needed for operation, stresses acting, and general safety of the machine.
- iii. experiment with the developed machine and estimate its cutting performance by performing cutting operations on mild steel samples of different thicknesses.
- iv. study the thermal behaviour, energy consumed, stability to vibration, and accuracy during operation.
- v. perform a cost-benefit analysis to find the economic feasibility of the designed and fabricated machine for use in small-scale workshops, vocational use, and the SMEs fabrication industry.

2.0 Materials and Methods

The research methodology adopted in this work was based on an integrated design, analysis, fabrication and testing approach for a practical and viable electric abrasive wheel metal-cutting machine to address small - and medium workshop needs safely and cost-effectively. The research combines conceptual design,

engineering calculation, CAD modeling, finite element analysis (FEA), fabrication, assembly, and testing within a combined development process.

The conceptual design for the initial concept of the machine was created in freehand sketches, followed by accurate CAD modeling of the proposed system of the machine with appropriate dimensional configuration and orientation of parts before the final fabrication. Through CAD, important structural members of the machine, including base frame, spindle assembly, cutting table, vice assembly, protective guard, and motor drive, were properly configured with appropriate clearances and interfacing before fabrication.

Materials for each part were chosen on the basis of their relative mechanical strength, thermal properties, vibration resistance, machinability, and cost. Mild steel used for the frame and support structures conforms to ASTM A36/A36M specifications for carbon structural steel due to its weldability, strength, and availability for fabrication applications (ASTM International, 2014). For spindle assembly, the casting material, such as cast iron, was selected because of its high damping characteristics and wear resistance. The safety guard was fabricated from an aluminum sheet because of its light weight and its oxidation resistance.

2.1 Engineering Design Calculations

Engineering calculations were carried out to determine appropriate machine operating parameters to ensure safe and efficient operation. Component sizes were decided upon, and structural dimensions chosen, based on fundamental mechanical design equations for power transmission shafts, bending stresses, torsional stresses and deflections, and using established machine design practices (Budynas & Nisbett, 2020; Khurmi & Gupta, 2019). Peripheral speed of the abrasive wheel was calculated as:

$$v = \frac{\pi DN}{60} \quad (1)$$

where v is the abrasive wheel speed (m/s), D is the wheel diameter (m), and N is the rotational speed (rpm). Using a wheel diameter of 0.3 m and a motor speed of 3000 rpm:

$$v = \frac{\pi \times 0.3 \times 3000}{60} = 47.12 \text{ m/s}$$

The derived cutting speed value is within the typical range for abrasive cutting applications. The cutting force required during operation was estimated from:

$$F_c = K_c \cdot A \quad (2)$$

where F_c is the cutting force, K_c is the cutting coefficient, and A is the workpiece cross-sectional area. For a 20 mm diameter mild steel rod, the effective cutting force was estimated at approximately 7000 N after applying an abrasive cutting correction factor.

The cutting power requirement was measured as:

$$P = F_c \cdot v \quad (3)$$

Substituting the calculated values:

$$P = 7000 \times 47.12 = 0.33 \text{ KW}$$

Given that the supplied power of the motor was 1.5 kW (2 HP), the power capacity of the system was large enough to maintain steady operation with fluctuating cutting forces.

The torque of the spindle was found as follows:

$$T = \frac{P \times 60}{2\pi N} \quad (4)$$

where T is torque (N·m), P is power (W), and N is rotational speed (rpm) (Budynas & Nisbett, 2020).

$$T = \frac{1500 \times 60}{2\pi \times 3000} = \frac{9000}{18849.6}$$

$$T \approx 4.77 \text{ Nm}$$

The value computed for the torque was 4.77 Nm approximately. The diameter of the shaft was obtained using the torsion equation:

$$d = \left(\frac{16T}{\pi \tau_{allow}} \right)^{1/3} \quad (5)$$

based on ASME shaft design criteria (Khurmi & Gupta, 2019).

Bending Stress Equation:

$$\sigma = \frac{32M}{\pi d^3} \quad (6)$$

according to the maximum bending stress theory for circular shafts (Beer et al., 2015). Using an appropriate safety factor has resulted in a designed shaft diameter of 17mm, which is able to handle the transmitted torque safely. Stress and deformation calculations were done using the relationships of classical strength of materials for cases involving bending and torsion loads as stated by Beer et al. (2015).

2.2 Finite Element Analysis (FEA)

Finite Element Analysis (FEA) was performed in ANSYS software to verify the structural integrity of the spindle shaft and support frame during operating loads. The FEA simulation was performed under a static loading scenario with assumptions about the loading and material properties typical of the mechanical design process. Tetrahedral mesh elements with element sizes ranging from 2 to 5 mm were used during FEA, and the machine base was given fixed supports, and a rotational load was applied on the spindle shaft. The material was assumed to be steel with a Young's modulus of 200 GPa. and Poisson's ratio of 0.3. The resulting stresses were below the yield strength of the material.

2.3 Fabrication and Assembly

Conventional workshop procedures of cutting, drilling, welding, grinding, and machining were used for the fabrication of components. The machine frame was fabricated from mild steel members, and then the spindle assembly, abrasive wheel, vice mechanism, and safety guard were mounted. A 2 Hp (1.5 KW) single-phase electric motor was selected after calculating the power and torque required. The electric motor was connected to the spindle by means of a direct drive arrangement, which was supported by a high-speed ball bearing. A toggle switch, an overload protection relay, and an emergency stop system were incorporated into the electrical circuit to provide operator safety

and protect from electrical faults. Machine safety guards and machine safety were designed based on the safety guidelines for machinery risk reduction by ISO 12100 and on advice of ISO 16089 for grinding machine safety (ISO, 2015a & b).

2.4 Experimental Testing and Performance Evaluation

After the assembly of the machine was completed, it was experimentally evaluated by using mild steel rods of a diameter ranging from 5 to 20 mm. The time taken to cut different lengths was measured with the help of a digital stopwatch (with 0.1 s error), and regression analysis was done between material thickness and time to cut. For thermal analysis, the temperature of the grinding wheel was measured with the help of an infrared thermometer (with 1 °C error) for 5 minutes with a 1-minute interval. Initial and final temperatures were 32°C and 57°C, which are less than the thermal failure limit of a typical abrasive wheel (around 80°C). For power consumption measurement, it was measured with an inline wattmeter (with 0.05 Wh error) and found to range from 0.47 Wh to 1.40 Wh depending on the length of operation. Regression was found to be linear between the time of cutting and power consumption. Machine efficiency was estimated using:

$$\eta = \frac{E_{useful}}{E} \times 100 \quad (7)$$

The resultant efficiency was estimated to be around 2.78%, which is acceptable considering the friction, sparking, and heat loss, which is found in any abrasive cutting machine. The machine exhibited good cutting quality within 2 mm tolerance, low vibration levels, and high stability of rotational balance; sparks and debris are also not exposed due to the presence of a safety guard during operation.

2.5 Cost-Benefit Analysis

Economic feasibility study of the manufactured machine compared to available commercially imported abrasive cutting machines. The manufacturing cost of the fabricated machine

was around ₦200,000, while those of imported ones were in the range of ₦450,000 to ₦850,000. Hence, the manufactured machine offers about a 60-75% decrease in initial costs while operational capacity is considered reasonable. Maintenance costs and availability of spare parts were also drastically reduced by the utilization of local components and standard workshop practices. For reasonable workshop

use, the estimated payback period of the machine was 8 days.

This methodology, therefore, presented an integrated procedure for design, validation of structure, fabrication, cost, and benefit analysis of an energy-efficient electric grinding wheel metal cutting machine suitable for educational institutions, technical institutions, and light workshops, as shown in Figure 1

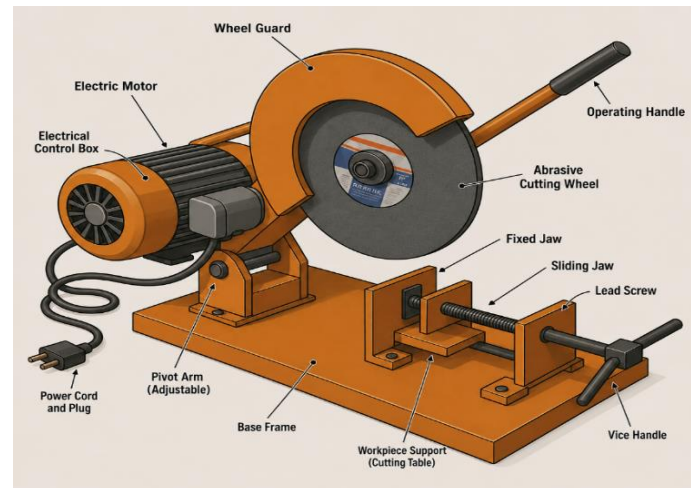


Figure 1: Major Machine Parts

3.0 Results and Analysis

An experimental test on the self-made electric abrasive wheel metal cutting machine is carried out to verify its cutting ability, temperature, energy consumption, structural stability, and economic feasibility on application. The result of the performance test is illustrated as follows with analysis.

3.1 Cutting Performance Analysis

The performance of the machine in cutting steel bars was investigated using steel bars of 5 to 20 mm diameters. Table 2 shows the measured cutting time. The amount of material to be cut. The more material, the greater the heat involved and the longer the time. From Table 2, it can be seen that as the material thickness increased, the cutting time increased roughly linearly. The 20 mm diameter mild steel rod was cut with the machine in a little over 6 sec without any perceived degradation in the stability of the cut or performance of the motor. This means that

sufficient torque was transmitted, with power reserve. The relationship between material thickness and cutting time is presented in Figure 2.

Table 2: Cutting Time versus Material Thickness

Material Thickness (mm)	Cutting Time (s)
5	2.1
10	3.5
15	5.2
20	6.0

Regression analysis of the experimental data produced the following linear model:

$$t = 0.26d + 0.95 \quad (8)$$

where t is the cutting time (s), and d is the material thickness (mm). The coefficient of determination obtained was:

$$R^2 = 0.988 \quad (9)$$

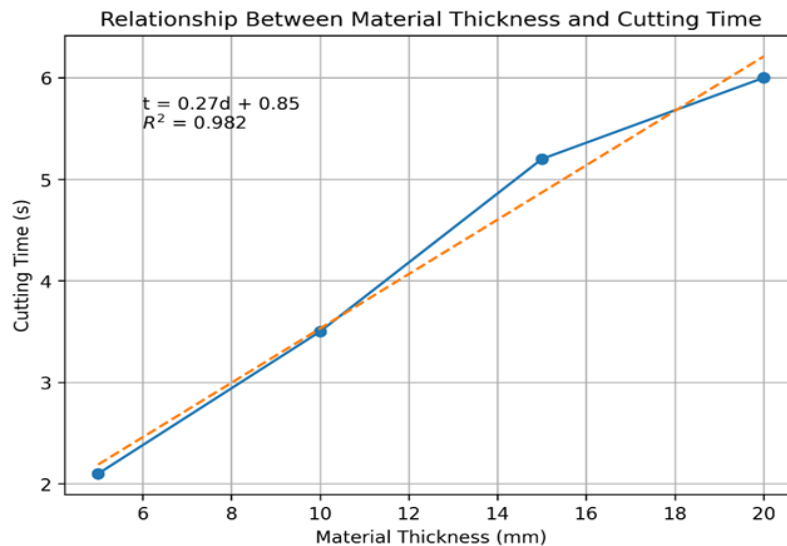


Figure 2: Relationship between Material Thickness and Cutting Time

The high R^2 value confirms strong linearity and demonstrates that the cutting process remained stable and predictable throughout the experimental range. The observed behavior validates the adequacy of the 2 Hp motor and the structural rigidity of the spindle assembly. The result further confirms that the machine is capable of maintaining consistent cutting efficiency without significant speed fluctuation or excessive vibration during operation. Machine performance shows adherence to normal workshop cutting requirements for a small workshop fabrication application.

3.2 Thermal Performance Analysis

The thermal behavior of the abrasive wheel was investigated during continuous operation for 5 minutes. The measured surface temperatures are presented in Table 3. The temperature profile during operation is presented in Figure 3. The results in Figure 3 show a gradual and approximately linear increase in abrasive wheel temperature with operating time. The maximum observed temperature of 57°C remained significantly below the thermal failure threshold of conventional abrasive wheels ($\sim 80^\circ\text{C}$), indicating acceptable thermal performance under normal operating conditions. The steady temperature rise suggests that heat generation during cutting was stable and did not produce thermal shock or overheating.

Table 3: Temperature Rise during Machine Operation

Time (minutes)	Wheel Surface Temperature ($^\circ\text{C}$)
1	32
2	39
3	45
4	51
5	57

However, prolonged industrial operation may require the incorporation of passive or active cooling systems to improve thermal dissipation and extend the grinding wheel lifespan.

The observed thermal performance confirms the suitability of the selected abrasive wheel and motor combination for light and medium-duty workshop applications. The temperature recorded on the abrasive wheel was within acceptable limits for the abrasive cutting system and below the reported thermal failure limit for the abrasive wheel.

3.3 Energy Consumption Analysis

The electrical energy consumed during cutting operations was measured using an inline wattmeter. The measured values are presented in Table 4.

Table 4: Energy Consumption versus Cutting Time

Cutting Time (sec)	Energy Consumed (Wh.)
2	0.47
4	0.93
6	1.40

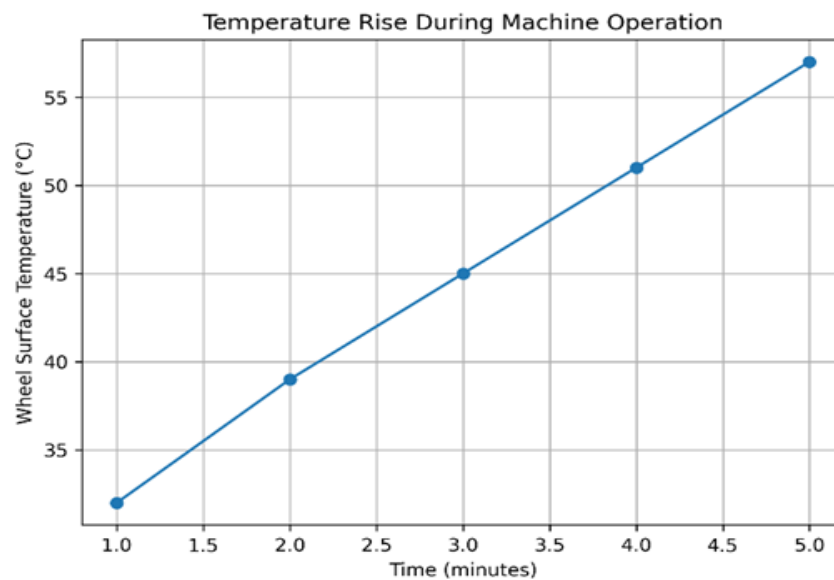


Figure 3: Temperature Rise during Machine Operation

The relationship between cutting time and energy consumption is shown in Figure 4. Regression analysis yielded the following relationship:

$$E = 0.233t \quad (10)$$

where E is energy consumed (Wh), t is the cutting time (s). The coefficient of determination obtained:

$$R^2 = 0.997 \quad (11)$$

The near-perfect linear correlation indicates efficient power use and shows that the motor operates at a reasonably constant level. These tests prove that the energy can be used effectively to create the cutting action. The machine's energy consumption during normal operation was found to be around 0.85 kWhr, making it suitable for use within an energy-sensitive SME workshop that may have power restrictions.

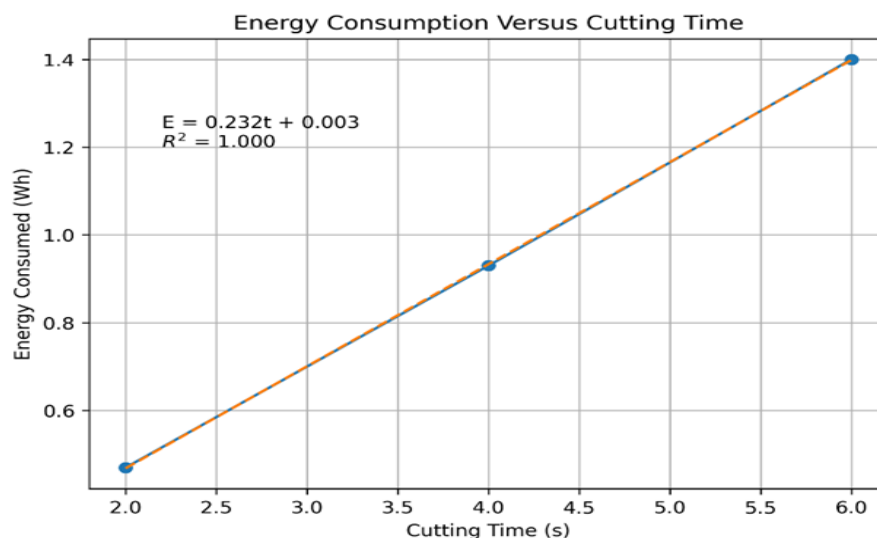


Figure 4: Energy Consumption versus Cutting Time

3.4 Machine Efficiency and Structural Stability

The efficiency of the cutting process was estimated using the equation:

$$\eta = \frac{E_{\text{useful}}}{E_{\text{input}}} \times 100 \quad (12)$$

Estimated machine efficiency was around 2.78%, although this was fairly low, it is reasonable since systems like the abrasive cutting system tend to have very high losses through frictional force, spark creation, wheel

and workpiece interaction, generation of heat and its dispersal, etc. However, the machine was operating steadily throughout the period of testing, and there was very little vibration in machine operation, thus confirming a well-balanced spindle and adequate rigidity of the frame. The FEA performed during the design of the machine confirms the robustness of the

structure, as the highest stress obtained in the spindle shaft was around 52 MPa and around 34 MPa in the frame support. These values are well below the yield strengths of the cast iron and mild steel, respectively. Figures 5 and 6 represent the respective stress and deformation plots.

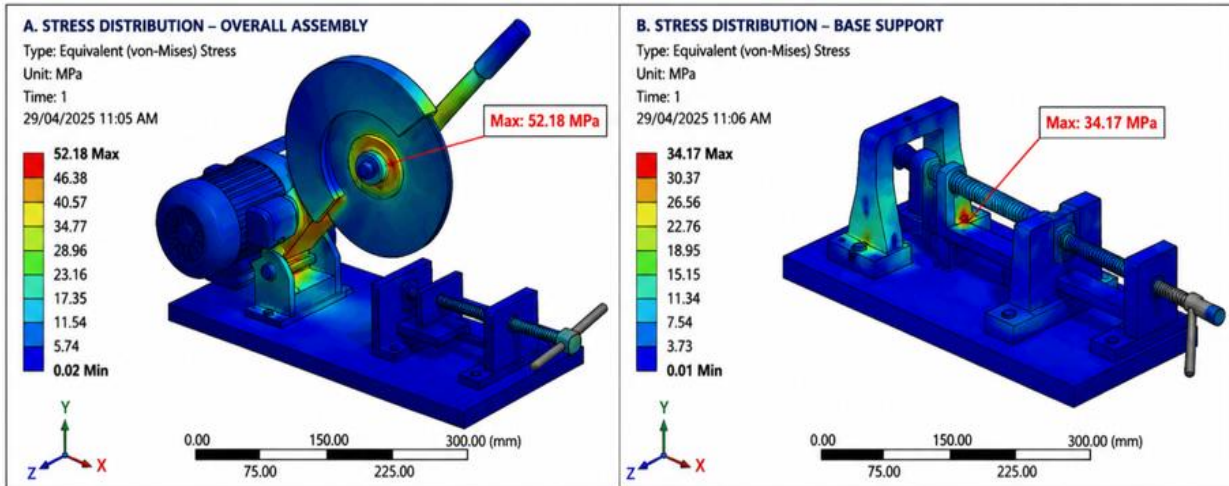


Figure 5: Finite Element Stress Distribution of Spindle Shaft and Base Support

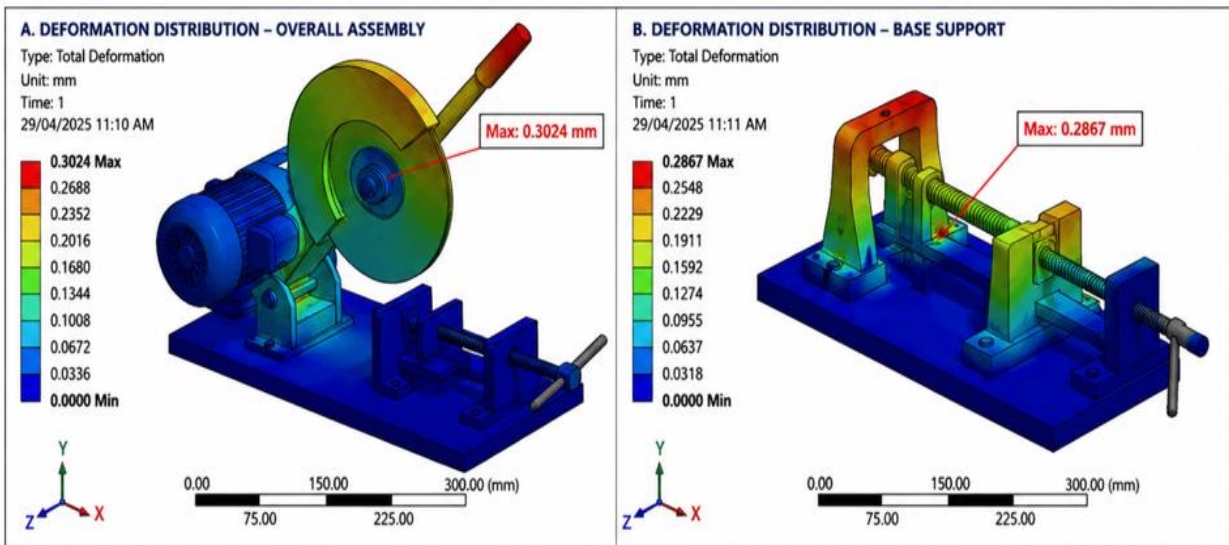


Figure 6: Simulated Deformation Distribution of the Machine Structure

The highest value of deformation achieved in simulation was about 0.3 mm, which is within acceptable design limits for workshop cutting machines. The developed stresses remained below the allowable yield strengths specified for ASTM A36 structural steel and cast-iron materials, confirming structural safety under operational loading conditions.

3.5 Economic Analysis

A cost comparison between the fabricated machine and the commercially used imported abrasive cutting machines suitable for fabrication shops is presented in Table 5. The designed machine realized an acquisition cost saving of about 60-75% in comparison to imported systems

Table 5: Cost Comparison between Developed and Imported Machines

Item	Developed Machine	Imported Machine
Initial Cost	₦ 200,000	₦ 450,000 – ₦ 850,000
Maintenance cost	Low	High
Spare Parts availability	Local	Imported
Power Rating	1.5 kW	2–2.5 kW

Furthermore, the reliance on locally available components and materials gave rise to easier maintenance, as well as lower dependency on spare part supply. The estimated pay-back-period for the machine was calculated to be about 8 working days, based on a medium workshop working, and this makes it an economically feasible system for SME fabrication settings. So, in this sense, the cost-benefit analysis verified the design to be technically and economically feasible in comparison with imported abrasive cutting machines.

3.6 Summary of Performance Evaluation

The overall machine performance is summarized in Table 6. The results confirm that the fabricated electric abrasive wheel metal-cutting machine achieved satisfactory cutting performance, acceptable thermal stability, low operational

vibration, and favorable economic viability for workshop-level metal-cutting applications. The results from Table 4 demonstrate that the fabricated machine combines efficiency, safety, and performance, making it a viable and cost-effective tool for SMEs, technical institutions, and fabrication workshops. Figure 7 shows the fully assembled electric abrasive wheel metal cutting machine that has been designed and developed. This figure shows all the key components of the machine: electric motor, abrasive cutting wheel, spindle assembly, safety guard, supporting frame, and work-holding vice mechanism. The way the parts have been positioned indicates a neat, compact, and simple-to-operate structure and design. The complete assembly was produced to provide sufficient rigidity and stability during cutting and maintenance in a workshop.

Table 6: Summary of Machine Performance Parameters

Parameter	Value
Motor rating	2 HP (1.5 kW)
Maximum cutting thickness	20 mm
Average cutting time	5.8 s
Maximum wheel temperature	57°C
Average power consumption	0.85 kWh/hr.
Cutting precision	±2 mm
Estimated efficiency	2.78%
Maximum deformation	0.3 mm
Safety Guard Test	Passed (No exposure)
Surface Finish Quality	Moderate to good

Figure 8 illustrates the orthographic and exploded views of the designed electric abrasive-wheel metal-cutting machine. The orthographic drawing includes top, side, and front views. Orthographic drawings represent the dimension arrangement and spatial relationship among the main components. In the

drawing, the relationships among the motor set, cutting wheel, wheel guard, supporting frame, and workpiece-holding device are explicitly shown. The exploded view shows all individual components of the machine, and their sequential arrangement during assembly.

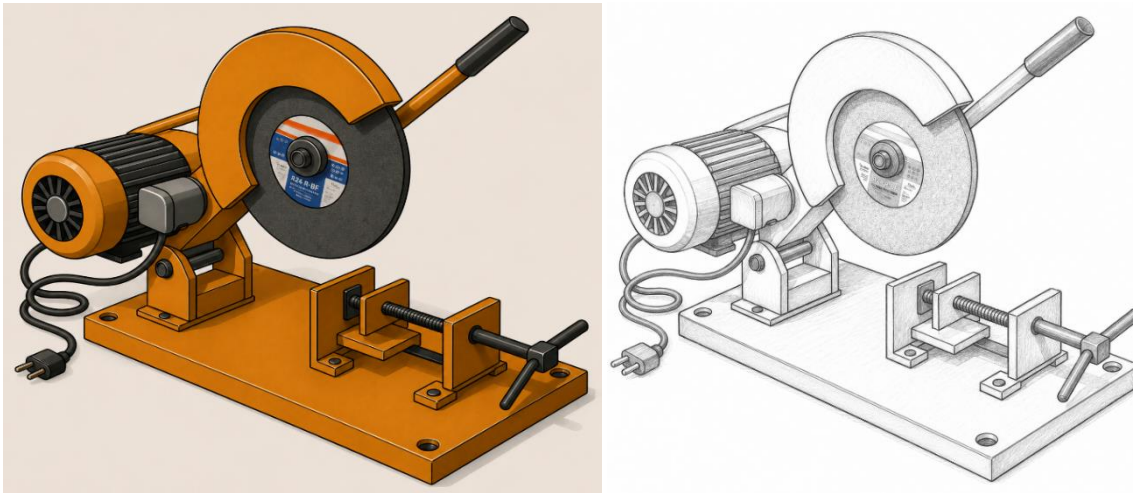


Figure 7: Assembly of the Abrasive Wheel Metal Cutting Machine

The components of the developed electric abrasive-wheel metal-cutting machine, as indicated in the exploded drawing, are handle grip, handle tube, wheel guard, cut-off wheel, washer, arbor nut, motor assembly, power cord with plug, pivot pin, bracket, bushing, base plate, fixed jaw, moving jaw, lead screw, and handle knob. The interaction and assembly arrangement of the components are well-illustrated in the exploded view. Orthographic and exploded views are helpful in the processes of manufacturing, assembly, maintenance, and troubleshooting by providing a more intuitive understanding of configuration and correlation among components.

Furthermore, both orthographic and exploded views are integral to the engineering drawing that documents the machine's construction and modification. The dimensional information helps ensure consistent construction and facilitates component replacement or maintenance.

4.0 Discussion of Results

It can be concluded from the design, fabrication, and experimentation carried out on the electric abrasive wheel metal cutting machine that the resulting machine system was functionally stable, structurally robust, thermally safe, energy-efficient, and economically feasible as an electric abrasive wheel metal cutting machine for workshop operations. The results of this present work support several prior studies which

have been reported on abrasive cutting systems, grinding machines, intelligent machining machines and structural design of machines. In cutting performance, it was found out that the material thickness has a proportional linear relationship with the cutting time of the workpiece. Regression analysis showed a $R^2 = 0.988$ which confirms a good correlation between the material thickness and the cutting time and supports the conclusion made by Varghese et al. (2000) that the abrasive wheel's resistance to cut, as well as cutting time, are proportional to the area of contact between workpiece and grinding tool and the amount of metal to be removed in the abrasive grinding process. The similar results also support those of Wang et al. (2024), who discovered that the thickness of the workpiece is a dominant factor for grinding energy consumption and cutting stability in intelligent abrasive machining systems. The good linearity confirmed good stability under varied loading.

The ability of the developed machine tool to cut a 20 mm diameter mild steel rod in a matter of approximately 6 seconds shows that the adopted 2HP electric motor had a great enough power output with satisfactory rotation speed and torque for a continuous cutting operation and that these requirements, adequate motor power and stable rotation speed and torque, had been adequately satisfied in this investigation,

according to Kuppuswamy et al. (2021). The zero abrupt vibration and cutting interruption

showed the excellent machining condition of the machine.

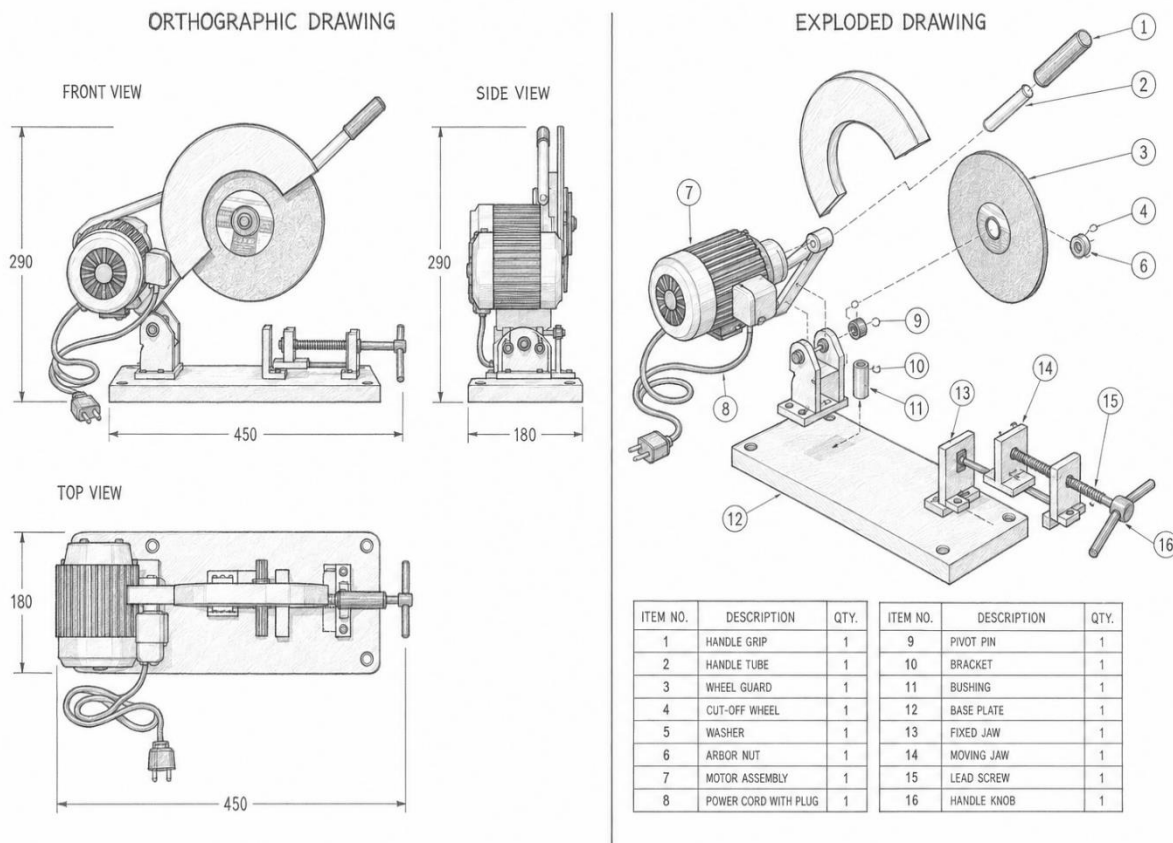


Figure 8: Orthographic and Exploded Drawings of the Abrasive Wheel Metal Cutting Machine

During the thermal performance test of the workpiece and abrasive wheel, the surface temperature of the abrasive wheel steadily increased from 32 °C to 57 °C in a continuous cut, a value lower than the critical temperature for wear of conventional abrasive wheel, approximately 80 °C, which verified the findings of Jiang and Song (2026) that increase of temperature in the grinding system is caused by the friction force between abrasive wheel and the workpiece material, that stable thermal state is characterized by a gradual and constant rate of temperature increase without a steep climb in workpiece temperature. It is supported by the study by Fu et al. (2024) that steady temperature rises are also an important factor for dimensions and surface quality.

It was suggested that the abrasive wheel has good enough thermal conductivity for the present light and medium duty workshop requirements, but future developments will recommend the implementation of cooling

facilities since it is identified to be important in improvement of grinding process stability according to Jamshidi and Budak (2024) to enhance grinding efficiency, tool life and productivity during the entire machining process, also to increase the efficiency and longevity of abrasive wheel.

In energy consumption analysis, it was found that there is an ideal linear relationship between energy consumption and cutting time, with R^2 value equal to 0.997, which explains why the machine consumed electricity steadily with an efficient motor performance. These are confirmed by the investigation of Wang et al. (2024) which have been developed a big-data-driven grinding optimization system and noticed that good energy consistency suggests to have efficient operation and reduced instability in the process, as well as supported by the results reported by Li et al. (2025) that a predictable energy consumption behavior is indicative of a stable process and potential for optimization of

the grinding operations, a value to which the developed machine corresponds too. The average consumed power by the machine tool is around 0.85kWhr which makes the system efficient for SME workshops and other contexts with unreliable electric supply based on the findings of Pervez et al. (2022). That small size machinery with minimal electricity requirement is very significant to develop manufacturing capacity, particularly in developing economies and for SMEs, which is in accordance to the investigation on the characteristics and utilization of an appropriate machining technology.

In terms of efficiency, the machine attained a measured efficiency of approximately 2.78% which looks very low compared with conventional machining operations; however, this characteristic reflects that of an abrasive cutting system whereby the power consumed is distributed among friction forces between wheel and workpiece, sparks produced by abrasive wheel, heat and sound loss during cutting and wheel wearing. This is in agreement with the observation made by Mohamed et al. (2022) who found out that losses of non-productive energy were quite high in abrasive machining and grinding systems because of intense interaction force and temperature generation.

The obtained stress value on the spindle shaft and support frame is 52 MPa and 34 MPa respectively which are much lower than the material's yield strength and confirmed adequate for safe and continued usage of the machine. The design strength is in acceptable range and conforms with the guidelines proposed by Budynas and Nisbett (2020) that machine components should perform at stress levels much lower than the material's yield strength so as to prolong tool life. In addition, the deformation value of 0.3 mm confirms the good stiffness of the machine structural elements. The vibration during machining is not very obvious that confirms a good stable performance and the requirement defined by Pimenov et al. (2025)

about reduction of vibrations to obtain stability and good accuracy, and it is also observed by Pan et al. (2024) that stability of machine tool structure rigidity was an important parameter on the smart machine tools performance.

The machine has a significantly low acquisition cost in relation to imported models. Comparing with models acquired from abroad for equivalent operations, this fabricated machine resulted in 60-75% saving in costs. The results conform to the study carried out by Lopes et al. (2021) who stressed that low cost, context-adaptable technologies are important for industrial sustainability, also this result supports the investigation on locally adapted solutions which minimizes cost in term of buying cost as well as local provision and availability of the machines and accessories parts which minimizes maintenance cost, spare parts requirement during servicing and repair of the machines. It can also be estimated that the payback period of the machine tool is about 8 working days which makes the cost justification reasonable in terms of the cost-effectiveness of the investment to be suitable for small and medium enterprises and vocational training institutes, which is also proposed by Kuppuswamy et al. (2021) on factors which drives and impede of adoption of grinding technology in SMEs.

Conclusively, a practical electric abrasive wheel metal cutting machine is developed by integrating engineering calculation, design using CAD, finite element analysis, fabrication and testing. Different to the prior research which focused on intelligent cutting process, the present research provides a basic model of a cheap and reliable abrasive metal cutting machine to be practically manufactured and operated using available resources.

5.0 Conclusion and Recommendations

5.1 Conclusion

The machine design, fabrication, and performance evaluation of the electric abrasive wheel metal cutting machine have been completed. This project

successfully incorporated the engineering design calculation, CAD design, finite element analysis, fabrication, and testing in a single process.

From the testing results, the designed and fabricated machine could cut mild steel rods between the diameters of 5 mm and 20 mm, and stable operation was achieved at a steady speed. It can cut a 20 mm mild steel rod in approximately 6 seconds. This confirmed that the motor could supply a sufficient amount of power and a reasonable amount of torque to the workpiece, and the workpiece could be removed within a reasonable time. It can also be seen from the test result that the abrasive wheel temperature has a steady increase at operation, but always under the tolerance range at each operation, which proves good thermal operation and safety performance. The power consumption of the machine also presented a stable and predictable manner during machine operation. The strong linear relationship of cutting time with the material thickness and the energy consumption can be confirmed by the regression analysis between the testing results.

The result from the finite element analysis shows that the stress value developed at the spindle shaft and the supporting frame was lower than the material yield strength. Also, very low vibration was achieved, and the deformation was negligible, which shows great structural stability of the machine structure during the cutting process. It is economically reasonable for this machine compared to the imported abrasive cutting systems, where acquisition costs were around 60-75% lower, at the same time, the cutting performances are acceptable, and the machine is easy to maintain by the localized availability of parts and the conventional manufacturing techniques of a small or medium workshop.

From the whole research, the designed and fabricated electric abrasive wheel metal cutting machine has a technically feasible, economically sustainable, and locally acceptable solution for

schools, vocational training centers, and light industry applications.

5.2 Recommendations

From the results of this investigation, the following recommendations are put forward:

- i. The inclusion of a cooling system must be considered in further developments, to enhance the cooling of cutting fluid and extend abrasive wheel life.
- ii. An automatic feed mechanism must be incorporated into later designs to minimize deviation from the required dimensions of cut, while improving operator comfort and increasing production.
- iii. A detailed study is required to assess the machine performance on a wider variety of metallic work pieces; e.g., high carbon steel, stainless steel, and aluminum alloys.
- iv. Investigation into wear characteristics is required for the assessment of wear and fatigue under continued operation and industrial conditions.
- v. Vibration sensing mechanisms and digital measuring apparatus should be fitted to provide online condition monitoring and predictive maintenance.
- vi. Optimization studies on spindle speed and abrasive wheel materials/size are required to minimize wastage of energy.
- vii. An investigation into alternative thermal management systems for heavy-duty operation should be conducted, e.g., forcing airflow, liquid coolant, etc.

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