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Research Article

Design and Fabrication of a Cost Effective Lab Rock Cutting and Polishing Machine

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Keywords

Cutting machine,
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Preparation of rock sample.

Abstract

To meet some testing specifications, rock samples taken from an in-situ rock mass must be cored and polished into standard sizes. The sample length, smoothness, diameter, and thickness are examples of such specifications. All of these specifications have an impact on the test result and the achievement of the test goal. As a result, rock polishing and cutting operations are required in the laboratory to prepare and work on various types of samples. Most of the time, these machines are built differently, which is efficient but costly, rigorous, and takes volume and shape in the laboratory. A specimen-cutting and polishing machine was designed and built to help researchers obtain mineral/rock specimens for strength testing. This machine is made up of an electric motor, a diamond cutting disc, and an electric pump for water cooling. To convert electrical energy into mechanical energy, a 1.15KW electric motor was used. A central electrical distribution grid provides alternating current to an electrical motor. The designed machine used a 380V, 50Hz electric motor with a rotating speed of 1.83 m/min and a torque of 109.38 KN. The cutting machine was designed and built to cut and polish different materials in order to obtain specimens for strength tests and structure inspection.

1. Introduction

Rocks are solid aggregates of one or more minerals, as defined by Klein and Philpotts (2013) [1]. The lithosphere, McCarthy (2013) [2] said, is the outermost layer of the Earth's solid surface, and it is composed of rock. They are made up of microscopic grains of different minerals that have been pressed together through a chemical reaction. The non-liquid portion of the Earth's crust is made up of rocks (McCarthy, 2013) [2]. Multiple minerals and organic compounds make up rock, as stated by Waples and Waples (2004) [3]. According to Mattern's (2014)[4] observations, rocks go through cycles of transformation from one form to another and from one location to another. Stone working, which includes grinding, polishing, and cutting, is an extremely old human activity that dates back to the beginning of time, as stated by Heldal (2009) [5]. Rocks are polished for a number of reasons, including to make them last longer and look nicer in finished applications (humans are drawn to shiny, clean surfaces) (Grant, 1978 [6]). In order to maximize efficiency and productivity, the stone cutting and polishing industry has adopted a highly mechanized and optimized approach. During rock strength tests, samples are cored, cut, and polished to allow for easy work in labs and the mining industry. In the course of sample preparation, it can be used to cut to a square or rectangle and polish small areas of surface.

Stone cutting machines, as Ogundele et al. (2014) [7] explain, were originally used to cut stones of varying sizes and shapes, hence the name. When deciding on a rock cutting machine, they recommended taking into account the rock's strength, the size of the rocks that will be generated, and the rock saw technology available. Shigley and Mishike (2001) [8] describe how the cutting design has been widely adopted in the United States and France as the cutting element in small size rock cutting machines. The design and construction of rock cutting machines are crucial due to their versatility.

In order to test the strength of rocks, specimen strips must be cut and polished using special machines. Precision cross-sectional cutting of copper, brass, steel, or non-metallic materials is another common application of a rock cutter. Using a thin abrasive wheel, precise control over the blade's cutting length is possible. Metallurgical laboratories rely heavily on cutter machines for cutting a wide variety of metallographic specimens. The machine can perform a smooth finish cut in either wet or dry mode, depending on the material being processed (Cutters are at extra cost). The specimen cutting machine can make cuts up to 200 mm deep in a variety of materials, including concrete, stones, tiles, soft and hard rocks (specify the size of the deep cut required in the specimen). The cutting, grinding, and polishing mechanisms developed in tribology have historically been applied to metals due to their specific, fundamental, and ubiquitous needs. This has contributed to the advancement of metal mechanization formulas and theories in a number of academic fields. However, this is now being applied to other substances, such as rocks and ceramics. Due to its strength, engine recommends using segments made from carburized diamond grains and metal powders when cutting and polishing rock materials. Our current stone polishing and cutting machines are effective, but they are inefficient due to safety concerns, time-consuming procedures, and the fact that most of them do not come equipped with a holder or clamp to hold the specimen to the abrasive or cutting tool, leaving the user vulnerable to abrasion injuries. Because most existing rock cutting and stone polishing machines are constructed differently, requiring more floor space in workshops, this study seeks to develop a single machine capable of both tasks. The purpose of this study is to develop a desktop rock polishing and cutting machine suitable for polishing and cutting rock core specimen samples needed for laboratory testing and usage. Finally, we'll be keeping an eye on how abrasion is affecting rocks on a microscopic level. Cutting rock samples in numerous Nigerian cities Creating laboratories for rock mechanics was difficult due to the lack of affordable and portable equipment. Most students have difficulty extracting samples from in-situ rock blocks for geotechnical and geomechanical property tests and analyses. Because the dimensions of tested rock samples must meet the outlaid size standard of the International Rock mechanic testing standard (ISRM). This project describes the design, production method, and development of a portable, multifunctional rock cutting/polishing machine. This paper discusses the cost implications and performance of a newly developed machine that was tested on rock samples at the Federal University of Technology in Akure, Nigeria.

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2. Review of Rock cutting and polishing machine principle

In the history of cutting, grinding, and polishing, tribology is utilized (Engin, 2013; Hogmark et al., 2000; Adams, 2014; Huang et al., 2021) [9-12]. Tribology is the study of the mechanisms of friction, lubrication, and wear, according to Engin (2013) [9]. Blau defines friction as that which generates heat and opposes the relative motion of two bodies over one another (Blau, 2001) [13]. Static friction occurs between stationary surfaces or bodies, while dynamic friction occurs between moving surfaces (Feynman et al., 1965) [14]. Lubricants are viscous fluids, such as air and water, that reduce friction between two surfaces and control the rate of wear (Szeri, 2010; Khonsari and Booser, 2017) [15-16]. In engineering, adhesive wear, abrasive wear, corrosive wear, and surface fatigue wear are the most prevalent types of wear (Swain et al., 2020) [17]. Wear on friction surfaces (w) is defined by Cellek and Engin (2016) [18] and Archard and Hirst (1956) [19] as being directly proportional to the applied load (W) and inversely proportional to the material strength (H), as shown in the equation: (1).

$$w = K \times W/H \qquad (1)$$

According to Kumar et al., the primary mechanism utilized in polishing machines is the utilization of abrasive force through the friction impact of high strength and wear-resistant properties (Kumar et al., 2020) [20]. According to them, the purpose of rock polishing is to create a smooth, reflective, and shiny rock surface. Due to their high abrasion resistance, diamond tools are commonly used for polishing rocks (Bulut et al., 2021; Konstanty, 2011; Li et al., 2021) [21-23]. According to Engin (2013) [24], polishing is the result of smearing a material onto a surface so that it fills the surface's voids; this material has a structure that is highly comparable to amorphous and loses its crystal structure. This coefficient is modified so as to Engin (2013) [24] also mentioned that there is continuous material loss during polishing of physically polished surfaces, as evidenced by the presence of visible scratches on the surface when abraded materials are observed. Wimmer et al. (2001) [25] proposes three polishing acceptances, the first being that surfaces always have thin scratches or joints, and the second being that during the polishing process, material is removed from the surface at a constant speed and in a layer that is removed from the surface. This layer is very similar to the layer transformed by abrasion. When compared, the similarities between ground and polished surfaces are evident. However, in the industry, horizontal and vertical rock polishing machines are distinguished. Because they require less floor space than horizontal polishing machines, vertical machines are typically the best option. Since materials are typically stored and handled vertically, vertical machines reduce the likelihood of handling and damage. Table 1 displays the components of a rock-polishing machine.

Table 1. Table Showing Components of an Industrial Polishing Machine

LY-6T Bridge Type Multi-Heads Stone Polishing Machine	
No of Heads (optional)	6pcs
Grinding Vertical Stroke	180mm
Worktable	1.3300×W880×H600
Water consumption	6 m3/hr
Power of main motor	7.5 × 6 Kw
Total power	50Kw
Overall dimension	8600 × 5000 × 2000
Gross weight	10.3 Tons
Processing width	100-1200mm
Processing thickness	6-20mm
Processing speed	5-6m/min

3. Materials and Methods

The materials used for this project are listed in Table 2, and include various components used for the design and fabrication of the cutting and polishing machine, as well as various laboratory and workshop tools and equipment used for the preparation of the fabricated components, test samples, and various rock samples chosen for the evaluation of the machine. The work flow diagram is depicted in Fig.1.

Table 2. Machine Components

S/N	Machine Component	Criteria for selection	Selected Material	Reasons of selection
1	Motor	Enough operating speed to power the cutting and polishing operations	Atlas electric motor speed of 1400rpm, 1hp power	Speed 1400rpm which was enough for our design, Power of 1hp.
2	Bearing	It should be able to stabilize the machine rotating when rotating	Shaft Bearing 25mm diameter	Allows rotation and stabilize machine frame
3	Filter	Filter size must be small enough to separate the chips from the coolant	Filter paper/cloth	Easy use, removal and installation
4	Metal Frame	It should be able to carry the entire load of the other components attached to it.	Galvanized iron, Angle iron	Low cost, efficiency, strength,
5	Cutting disc	It should be hard enough to cut rock	Diamond teeth cutting disc	Strength, agility, rotatable prowess

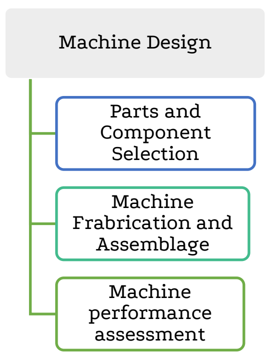

Figure 1. Flow chart of the study

3.1. Materials and Components Used

- **Electric motor**

An electric motor converts electrical energy into mechanical energy for the rotating shaft, which is used to polish and cut rocks. It rotates the shaft in a horizontal circular motion while holding the abrasive and cutting disc. An Atlas Mechanics electric motor (See Fig.2) with single phase 1horse power and a speed of 1400rpm was used in the development of the proposed machine.

Figure 2. Electric Motor

- **Abrasive disc**

When grinding or polishing, a diamond abrasive polishing disc is typically used to achieve the best results. However, because a diamond abrasive disc is not available, we use a corundum abrasive disc.

- **Cutting disc**

The abrasive disc is made of high carbon steel and has diamond teeth embedded in it. It has a concentric grooved center to help secure the disc to the spindle.

- **Metal plates**

Metal plates are commonly used for machine body parts and are typically made of medium carbon steel. Machine body parts would be made of 2mm thick metal plate. Sheet metal can be cut with a wide range of tools, from hand tools like tin snips to very large powdered shears. The weight per square foot inch of thickness is 41.82 pounds.

- **Angle bars**

Angle iron comes in a variety of standard sizes, which are typically denoted by naming the length of one side. Although we speak of four-inch angle iron, the angle bar used is one-inch (2.54) angle iron.

- **Pipes**

The water from the rock polishing machine's basin will be drained using hollow lead pipes. They will be made of non-corrosive materials such as lead or rubber. When in contact with water, the lead pipes allow for the constant passage of water through them without corroding. During the polishing process, the pipe will generally serve as a conduit for used water to be recycled and pumped back into service.

- **Bolt and nuts**

The fabricated components were assembled and fastened with bolts, nuts, welding, riveting, and brazing where applicable to ensure the firmness of the parts while in operation. System of belts and pulleys A pulley is a wheel mounted on an axle or shaft that is designed to support and change the direction of a belt or taut cable that aids in the transmission of power via the belt - in this case, from the motor to the shaft.

- **Plate Cover**

To prevent dust from accumulating on the machine's surface, the machine was covered with a plate cover to prevent unwanted materials from entering the machine cavity.

3.2. Design Consideration

Rock polishing and cutting come in a variety of shapes and sizes, depending on the intended use, the size of the piece, and the materials used. The following factors are considered: strength, size, weight, volume, rigidity, stability, and functionality. The majority of these characteristics have an effect on the machine's overall design, either directly or indirectly. The goal of this study was to develop a rock polishing and cutting machine that used the same electric motor and had disengaging grids that could do both polishing and cutting at the same time and disengage any of them if necessary. However, it was determined that such a design would be too time-consuming and costly after careful consideration of time, resources, cost estimation, and volume of work. To make things easier, the cutting tool's configuration was changed from vertical to horizontal, as shown in Fig.3. Because of the simplified design, the user will only need to change the machine's disc depending on the operation to be performed (either polishing or cutting). The study design is depicted in Fig. 3. The machine dimensions and skeletal view are depicted in Fig.4.

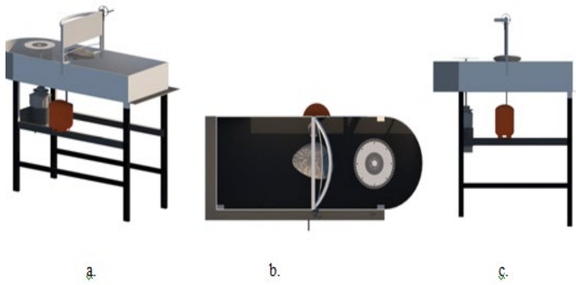

Figure 3. Machine Design, a. 3-D Diagram of Machine, b. Plan View of Machine, c. Side view of Machine

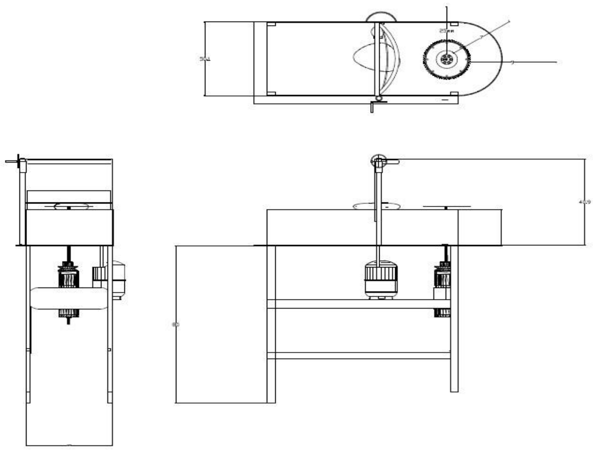

Figure 4. Dimensions and skeletal view of Machine

3.3. Machine Production

Table 3 presets the procedure sequence in the production of different parts of the machine. Table 4 presents the cost of materials and Engineering Bill of the project.

3.4. Cost of Materials and Bill of Engineering

The proposed machine parts cost are presented in Table 4 respectively.

Table 3. Production of Machine Frame

Operation No	Process	Equipment Used
1.	Marking out and cutting of the I I. Base plate 801mm x 501mm (galvanized steel of 2mm thickness) II II. Side plates of 450mm × (2 pieces of galvanized steel) III III. front plates arc diameter of 300mm	Measuring tape, Hack saw and Power hack saw
2.	Joining of the angle iron to form the skeletal base of the machine	Arc welding machine
3.	Marking out and cutting the skeletal bars to create opening for the shaft	Arc welding machine
4.	Screw the bearing to the skeletal base of the machine, while mounting the shaft the bearing of the machine	Bolts and nuts
5.	Mounting the motor to the skeletal base of the machine	Spanner, bolts and nuts
6.	Connecting by pulley system the motor and the rotating shaft	
7.	Mounting the cutting disc/polishing disc of dimeter 7” to the shaft.	nuts
8.	Painting of the machine	Brush and Aluminum Paint

4. Results and Discussion

4.1. Result of the fabricated machine

Fig.5 shows the completed machine design and fabrication. Fig.5a shows the plan view of the machine revealing the rock cutting blade and the adjustment lever.

4.2. Machine testing

The granite rock sample was used for cutting test; the sample was mounted on the clamp to avoid the movement of the specimen during working operations as shown in Fig. 6b.

a. b.

Figure 5. Machine Fabrication view

Table 4. Cost of materials and Engineering Bill for the project

S/N	Component	Unit size	No	Price (₦)	Material
1	Cutting Disc	7” dia	1	2,500	Diamond plated teeth disc, mild steel
2	Polishing Disc	9” dia	1	7,500	Corundum abrasive disc
3	Angle Iron			7,000	Galvanized iron
4	Bearing	25mm diameter	2	5,000	PTFE, Cast iron
5	Shaft	25mm diameter	2	6,000	Mild Carbon Steel
6	Pulley		1	5,000	Galvanized iron
7	Belt		1	500	rubber
8	Bolts and Nuts		10	1,500	Medium carbon steel
9	Water Pump	220v, 50Hz, 450L/H	1	15,000	Plastics, rubber,
10	1” Angle Iron			1,500	Galvanized iron
11	¾ flat bar			1,000	Galvanized iron
12	2mm plate			10,000	Mild carbon steel
13	6mm plate			3,000	Mild carbon Steel
14	Paint and body filler			5,000	Paint Spray,
15	Electrode			3,500	
16	Electric motor	1hp, 220v, 1400rpm	1	90,000	Cast iron for the housing, mild steel.
Workmanship				50,000	
Miscellaneous				10,000	
Total				224,000	

Figure 6. Pictures of the machine set up, polished sample and cutting samples

Fig. 6 c shows the cutting result of the machine and Fig. d-e presents the cutting and polished rock sample from the machine. The machine spindle speed which is the speed of the shaft that rotates the cutting and polishing disc was calculated using Eq. 2.

$$V = \frac{\pi DN}{60} \tag{2}$$

Where V is the speed, D is the diameter of spindle and N is the revolution per minute of motor

For the machine, D=0.025m, V=1400rpm

V = (0.341×0.025×1400)/60

V = 1.83 m/min

Rated Torque, t = (HP × 746W) (N × 2π/60)

Where HP = Horsepower of electric motor; = 1HP, N = Revolution per minute electric motor = 1400rpm

T = (1 × 746) (1400 × 2π/60)

T = 109.38KN

Maximum Power Output of the machine = Service factor × HP

Service factor for many electric motors is given as 1.15

Machine maximum Power Output = 1.15 × 1 = 1.15 KW

5. Conclusion

The importance of rock sample dimension accuracy during the geotechnical and mechanical tests had been revealed by several authors. Laboratory geomechanical tests on rock mass are usually done on the rock purposive sample also called the intact rock. To improve the laboratory test result through accurate sample dimensioning, this paper presents the new innovative machine developed for rock sample cutting and polishing. The machine that was built was applied to cut rock core and polish rock samples. The machine produced highly accurate cutting length and smooth polishing. The materials used are locally available, and a water flushing system was installed to cool the cutting process and remove the rock cutting from the cutting surface to avoid the heat, wear, and tear. It is recommended that an electric motor with a speed greater than 2000rpm be used to replace the machine's electric motor in order to achieve faster and finer results for both polishing and cutting. The developed machine was tested with a rock sample and found to give better results at a quicker time with a lower operation price.

Declaration of Conflict of Interests

The authors declare that there is no conflict of interest. They did not get any financial supply, interest, and no personal relationships that could impact the work reported in this paper.

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