Nigerian Journal of Engineering, Vol. 30, No. 2, August 2023, ISSN (print): 0794 – 4756, ISSN(online):2705-3954.

Nigerian Journal of Engineering,
Faculty of Engineering, Ahmadu Bello University, Zaria, Nigeria
journal homepage: www.njeabu.com.ng

Design and Fabrication of Variable Speed Abrasive Grinding and Polishing Machine for Metallographic Sample Preparation

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Research Article

Abstract

Polishing machine is one of the important equipment for preparing the surfaces of metallic specimens for metallographic examinations. This is to ensure a flat, smooth and mirror-like surface before loading on the metallurgical microscope for viewing and determination of their - microstructure. The machine designed and constructed was principled on using locally available materials for its fabrication. The machine components consist of rotating shaft, pulleys, belt, electrical powered motor and the light aluminium alloy polishing disk plate, bush bearing, pillow bearings enclosed in metal case of the fabricated machine. The test-running and assessment of the machine was carried out at different speeds, grits of abrasive papers and on variety of materials (metal alloys, composites, plastic, ceramics) for both dry and wet operating conditions. Also, testing of the machine was carried out with and without specimen on the rotating table for grinding and polishing. The operation of the machine was found to be safe and simple to operate at a reduced minimum maintenance cost. The specimen size should not be less than 25mm in diameter by 10mm thickness for easy hand held polishing operation.

doi: 10.5455/nje.2023.30.02.02

Keywords
Grinding; Polishing; Machine fabrication; Sample preparation; Metallography

Article History
Received: – April, 2023
Reviewed: – June, 2023
Accepted: – June, 2023
Published: – August, 2023

1. Introduction

Good surface premixed on adequate choice of preparation method is fundamental in metallography (Belan, 2012; Kallol, 2016) for effective and reliable results to be obtainable from different methods of characterisation such as transmission electron microscopy (TEM), scanning electron microscopy (SEM) and optical microscopy (OM). These fundamentals, their peculiarities and applications have been discussed at large over the decades in various available literatures (Bryant *et al., 1988;* Gwynn and Richards, 1995; Goldstein 2003; Argast and Tennis, 2004; Bullen, 2010; Erinle *et al.,* 2011; Weilie *et al.,* 2013; Davidson and Cummings, 2015).

Laboratory polishing machine is an equipment used for grinding and polishing of surfaces metallic and non-metallic specimens before the examination of their microstructure with the use of metallurgical microscopes in the laboratory. The machine is used to accomplish a mirror-like appearance on metals and other non-metals after grinding has taken place (Erinle *et al*., 2011). In both mineralogy and metallography, polishing effects defect-free surface for microstructural examinations under metallurgical microscopes (Venkannah, 2004). The initial surface condition of the specimen dictates the various types of abrasives to be used. Grinding may start with a rough abrasive grit grade such as 60 or 80 grit grade and subsequently to 220, 320, 400 and higher grit abrasives, till completion. There are different categories of abrasive grit media used for polishing and grinding of metals. Emery papers of different grit sizes such as 100, 120, 200, 400, 600, 800 grits are used for the grinding while 1000 and 1200 grit grades are used for polishing. The lower the emery paper number, the coarser the grit grade and the higher the emery number, the smoothest the grit grade.

Several models of laboratory polishing machines have been developed so far. However, they are costly due to the fact that they are imported and making of the machine locally is not being encouraged as a result of the attitudes to local products. The rationale behind this research work is to design and fabricate a portable laboratory-sized polishing machine that will be effective in grinding and polishing of metallic and n0n-metallic specimens. More so, in order to make it available for use in metallographic laboratories of various institutions willing to acquire the technology. Observations on previous metallographic polishing machine produce locally revealed that the major setback they had are the big sizes, heavy weight and uncontrolled noise vibration. As a result of this, the reduced weight and size factors were taken into consideration in the newly designed and fabricated machine for easy handling and portability. The present designed work ensured less vibration effect thereby reducing the noise when in use. The local fabrication reduces dependency on importation resulting in saving foreign exchange and more importantly, encouraging local technological development.

At a time like this, when importation is increasingly more difficult and expensive due to foreign exchange policy, getting facility of this type available for research and practical purposes is faced with serious challenges. Accessibility to research and experimental equipment are essential to any scholar, be it student or researcher and quality control units of any engineering firm and institutions. In finding a solution, there is the need to improvise. Hence, meeting up with these challenges are the motivation behind the conceptualization of the research. Thus, for research and students' training, the work is envisioned to entail the design and fabrication of a portable, light-weight, vibration-free dual purpose machine for grinding and polishing operations in metallographic studies.

2. Materials and Method

2.1 Design and Fabrication

2.1.1 Grinding and grinding media

Grinding is done to remove damage from cutting, planation of the specimens, and to remove other materials like oil or grease may affecting the surface of the specimen. It is achieved by abrading the surface of the specimen through succession of process using progressively finer abrasive grits. Grit sizes that ranged from 60 to 150 mesh are usually regarded as coarse abrasives while the grit sizes from 180 mesh to 600 mesh as fine abrasives. It is a cold working process of which the extent is dependent on the hardness of the specimen. This may be about 10 to 50 times the depth of penetration of the abrasive particle. It is important that the directions of grinding be changed by 90^o in every stage of the grinding so as to ease complete elimination of the previous grinding scratches found by visual assessment. This is because the effectiveness of grinding usually has effect on the microscopic examination. Cleaning at every stage of grinding is desired and always helpful**.** Examples of grinding media include among others, silicon carbide (SiC), diamond particles, emery (Al_2O_3- Fe_3O_4) and aluminium oxide (Al_2O_3). The abrasives are either in powdered form or bonded to nylon or paper and made in form of disks, belts or sheets in different sizes (Kallol, 2016)**.**

2.1.2 Polishing **and** polishing Nylon Cloths/Paper

Polishing is the final step in specimens' surface preparation in order to obtain accurate metallographic examinations as well as interpretation in both quantitative and qualitative. In polishing, care should be taken to avoid introducing extraneous structure like staining, pitting and inclusions unto the surface. The final stage of the polishing normally involve using of nylon cloths or paper-covered laps with appropriate polishing abrasives, mostly Al_2O_3 slurry on a vibrating or rotating disk with specimen held firmly on it in a dust-free area (Kallol, 2016). There are three types of polishing nylon clothes which are woven, non-woven and flocked.

2.2 Design Computations

Machine components' parameters:

a) Polishing pad diameter: 200 mm (disk)
b) Rotation rate: 1400 rev/min
c) Motor: IP44 BINS.CR; single phase 1 HP: 0.75 kW, 220 V, 50 HZ

Pulley and Belt design

i. Determination of the rotation speed is shown in equation 1:

$$\frac{N_1}{N_2} = \frac{D_2}{D_1} \quad (1)$$

Where:
N_1 = Speed of the motor (rev/min)
N_2 = Speed of the polisher (rev/min)
D_1 = Diameter of the motor pulley (mm)
D_2 = Diameter of the polisher pulley (mm)

Data:

N_1 = 1500 rev/min, D_1 = 80 mm, D_2 = 60 mm, N_2 = 2000 rev/min

Therefore, the maximum speed for polisher N_2 is 2000 rev/min

ii. Tension in the belt:

T_1 = Tension in the tight side of the belt in Newton(N)
T_2 = Tension in the slack side of the belt in Newton (N)

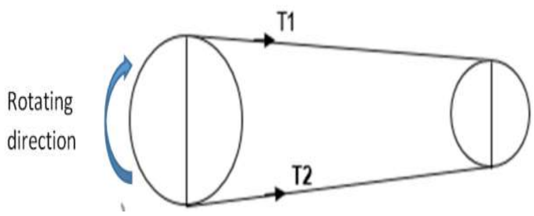


Figure 1: A Simple Belt and Pulley Drive

The tight side of the belt is usually at the top and the bottom while the centre line may be horizontal, vertical or inclined as seen in equations. 2 - 4.

$$2.3\log\left[\frac{T_1}{T_2}\right] = \mu.\theta.\mathrm{cosec}\beta \quad (2)$$

$$\theta = 180° - 2\alpha \quad (3)$$

$$\sin\alpha = \frac{R-r}{c} \quad (4)$$

Where:

μ = Coefficient of friction between belt and pulley
θ = Angle of contact on the motor pulley (radian,rad)
β = Groove angle of the pulley (degree,°)
α = Coefficient of increase of the belt length per unit force (degree,°)

R =Radius of the motor pulley (mm)
r =Radius of the polisher pulley (mm)
c =Centre distance between the two pulleys

Centrifugal tension T_c is the force that usually causes the belt to slip from the pulley and reduces the power that may be transmitted (equation 5). The speed of the V-belt must be 5 to 50 m/s.

$$T_c = mV^2 \quad 5$$

Maximum tension T, according to Khurmi and Gupta (2004), is highest tensional force that can act on the belt.

$$T = \sigma A \quad (6)$$
$$T_1 = T - T_c \quad (7)$$
$$V_1 = \frac{\pi N_1 D_1}{60} \quad (8)$$
$$V_2 = \frac{\pi N_2 D_2}{60} \quad (9)$$
$$V_1 = V_2 = V \quad (10)$$
$$m = \rho \times A \times L \quad (11)$$
$$A = b \times t \quad (12)$$

T_c = Centrifugal Tension of the belt (Newton, N)
T = Maximum Tension of the belt (Newton,N)
m = Mass of the belt per meter length (kgm^{-1})
V = Belt velocity (ms^{-1})
ρ = Belt density (km^{-3})
A = Cross sectional area of the belt (mm^2)
b = Belt width (mm)
t = Belt thickness (mm)
α = Allowable stress (N/mm^2)

2.2.1 Design analysis of the shaft:

Shaft, a solid or hollow in cross section is the rotating element of the machine that transmitting power from one place to another (Ajibola *et al.,* 2020, 2021a,b, 2022). The shaft is subjected to torsional, axial and bending loads and shaft mostly used are usually produced from medium carbon steel.

Design Assumptions:

a) Fatigue and shock are considered
b) The belt on the pulley is at angle 45°

The design of shaft made from ductile material like medium carbon steel is usually based on strength. This is controlled by the maximum shear theory according to Shugley (1980) and Ajibola et al. (2020, 2021a,b, 2022). However, the maximum permissible shear stress including the allowance for keyway for the mild steel material is 42 Nmm^{-2} in accordance with Khurmi and Gupta (2004). Consequently, the shaft of this polishing machine due to torsional load is only subjected to twisting moment or torque as a result of the belt drive employs to transmit power.

The torque T for the belt drive is given by equation 13

$$T = (T_1 - T_2) R \quad (13)$$

Where: T_1 = Tension in the tight side of the belt
T_2 = Tension in the slack side of the belt
R= Radius of the motor pulley
T = Twisting moment or torque pulley (Nm)

Torsion equation in accordance with Khurmi and Gupta (2004) is given as:

$$\frac{T}{J} = \frac{\tau}{r} \quad (14)$$

Where:
T=Twisting moment of the torque
J= Polar moment of inertia of the shaft about the axis of rotation (mm^2)
τ = Torsional shear stress (Nmm^{-2})
r= Distance from neutral axis to the outermost fibre

$$r = \frac{d}{2} \quad (15)$$

Where:
d is the diameter of the shaft (mm)

For the machine's efficiency, the shaft's diameter of the polisher will be twice the shaft of the motor shaft.

2.2.2 Design analysis of the key:

The key, made of mild steel, is designed to prevent relative motion between the shaft and the hub by inserting it parallel to the axis of the shaft in the keyway. The key is subjected to significant crushing and shearing stresses.

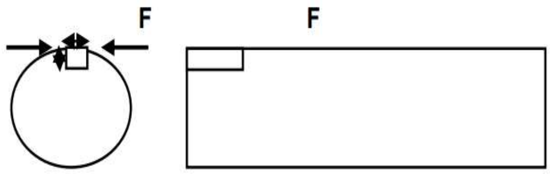


Figure 2: Design analysis of a Key

Assumption:

It can be assumed that the acting force is acting tangentially to the shaft to produce both shear and compressive stresses in the key in accordance with Shugley (1980).

Shear stress = Force/Area (Nmm^{-2}) (Khurmi, 2004)

$$\tau = \frac{F}{A} \quad (16)$$
$$F = \tau \times A \quad (17)$$

Cross sectional area = length × width (mm^2)
A = l × b
Torque = Force × radius (Nm)

$$T = F \times r \quad (18)$$
$$T = \tau \times r \times A \quad (19)$$

Where A = l × b

$$T = \tau \times r \times l \times b \quad (20)$$

2.2.3 Design analysis of Power transmitted per belt in (Equ. 21)

P = Power transmitted in Watt (W)
T_1 = Tension in the tight side of the belt (N)
T_2 = Tension in the slack side of the belt (N)
V = Belt velocity m/s^1

$$P = (T_1 - T_2)V \quad (21)$$

Table 1: Design Parameters calculation

Parameters	Data:	Formulae	Values
Maximum tension, T	$\sigma = 1.7\ \mathrm{N/mm^2}$ (For rubber belt; Assuming: $b = 15$ mm, $t = 10$ mm, $A = 150\ \mathrm{mm^2}$	$T = \sigma A$	255N
Mass of the belt, m	$\rho = 1250\ \mathrm{kgm^3}$, Rubber density; $A = 150 \times 10^{-6}\ \mathrm{m^2}$,	$m = \rho \times A$,	0.1875 $\mathrm{kgm^{-1}}$
Belt velocity, V:	$N_2 = 2000$ rev/min, The speed should not exceed 2000rev/min	$V = \frac{\pi N_1 D_1}{60}$	6.284 m/s
Speed centrifugal tension, Tc:	$m = 0.1875\ \mathrm{kgm^{-1}}$ $v = 6.284\ \mathrm{ms^{-1}}$	$T_c = mv^2$	7.40 N
Tension in the tight sideT_1	$T = 255$ N $T_c = 7.40$ N	$T_1 = T - T_c$	247.56 N
Coefficient of increase of the belt length per unit force,α	$R = 40$ mm $D_2 = 60$ $C = 300$ mm (Assumption) Recall: $\sin\alpha = \frac{R - r}{c}$	$R = \frac{D_1}{2}$	$R = 40$ mm $r = 30$ mm $\alpha = 2°$
Angle of contact(θ):	Recall that: $\alpha = 2°$	$\theta = 180° - 2a$	$\theta = 3°$ convert to radian that will be 3 × 0.0175 = 0.054 rad
Tension in the slack side (T_2):	$T_1 = 247.56$ N $\mu = 0.3$, For rubber material $\theta = 3°$	$2\beta = 30°$, Groove angle of the pulley $2.3 \log \frac{T_1}{T_2} = \mu\theta \operatorname{cosec}\beta$	$\beta = 15°$ $T_2 = 7.6$ N
Power transmitted, P	$T_1 = 247.56$ N $T_2 = 7.6$ N $V = 6.284\ \mathrm{ms^{-1}}$	$P = (T_1 - T_2)V$	1508 W
Length of the belt, L	$R = 40$ mm, $r = 30$ mm, $C = 300$ mm	$L = \pi(R - r) + 2C + \frac{(R-r)^2}{C}$	820 mm
Torque, T	$T_1 = 247.5$ N $T_2 = 7.6$ N	$R = \frac{D_1}{2}$ $T = (T_1 - T_2)R$	$R = 40$ mm $T = 9598$ Nm
Shaft diameter, d	T = 9598 N $\tau = 42\ \mathrm{Nmm^{-2}}$ (Being mild steel, the maximum stress permissible with key way allowance is 42 $\mathrm{Nmm^{-2}}$	$\left(r = \frac{d}{2}\right)$ $\left(j = \frac{\pi d^4}{32} \mathrm{mm^4}\right)$ $\frac{T}{J} = \frac{\tau}{r}$ $T = \frac{\pi \times 42 \times d^3}{16}$	$d = 10.51$ mm
Torque for motor shaft, T	$d = 10.51$ mm	$\frac{T}{J} = \frac{\tau}{r}$ $T = \frac{\pi \times 42 \times d^3}{16}$	$T = 9574$ Nm
Length l of the key for motor shaft,	$T = 9574$ Nm Basef on Khurmi and Gupta (2004), for a 21 mm diameter shaft, the width b thickness t of the key should both be 4.5 mm each, r = 5.255 mm	$T = \tau \times r \times l \times b$	l = 9.66 m

Torque for polisher shaft, T	$T = 42\ Nmm^{-2}$ $d = 21\ mm$	$\frac{T}{J} = \frac{\tau}{r}$ $T = \frac{\pi \times \tau \times d^3}{16}$	$T = 76372\ Nm$
Length of the key for polisher shaft, l	$T = 76372\ Nm$ According to Khurmi and Gupta (2004), for 22 mm diameter shaft, the width b and thickness t of the key b are 16 mm and 14 mm respectively $r = 10.51\ mm$	$T = \tau \times r \times l \times b$	$l = 10.81\ mm$

2.3 Design Parameters

For engineering services, abundant quantities of materials are accessible for applications. However, the choice of these materials is determined mostly by the overall performance of the system as it is the final practical decision in the design process. The chemical, physical and mechanical properties of the materials are usually considered as the basic parameters that informed their selection. The properties considered included availability, cost effectiveness, tensile strength, rigidity and/or flexibility, thermal, corrosion resistance e.t.c. The function, objective and the constraint of each unit of the polishing machine were considered in the selection of the candidate material (Ashby, 1999). This was used in selecting appropriate material for the fabrication of the laboratory polishing machine.

2.3.1 The Structural Frame

The function of the polishing frame was to provide housing for the component such as the electric motor, the shaft, the two pulleys, the belt and the ball bearing. It provided rigidity, strength, ability to carry its own weight and ability to retain high strength even after shaping. The constraint considered was cost. The polishing frame requires a material that is durable, moderately strong and that can withstand its own weight. The material should also be easily fabricated, readily available and not expensive. These served as the basis for the choice of material that was eventually recommended for the design of the polishing frame of the machine.
Hence, galvanized steel was used in the fabrication.

Cost Price: The prices of the materials chosen were relatively cheap. The materials selection table and costing are presented in Tables 2 and 3.

Weldability: To enhance proper fabrication by joining of the flat sheets; the material must be easy to weld.

2.3.2 The rotating disc

The function of the rotating disc is to hold the emery paper that will effect the grinding and polishing of the metals so as to give a mirror-like appearance. This was determined by considering some factors such as the diameter and speed of the rotating disc. The design factors that influenced the selection included the strength, corrosion resistance. The major constraints considered were cost and availability. Since cost is a crucial factor, locally available candidate material was given consideration.

2.3.3 The shaft design

The purpose of the shaft is to transmit rotational motion from the pulley to the rotating disc (Ajibola *et al.,* 2020). The set objective is the ability to resist the stress and bear the loads of other components. It should also be able to survive the bending of the torque moment as well as the compressive forces from the weight of other attached components weight. Generally, Cost and availability of the material was a major constraint considered in selecting the appropriate candidate material.

The cover plate: The cover plate used was made of thin mild steel sheet. The sheet metal was cut with the use of the guillotine machine into various sizes required for the production of the polishing machine. The sheet plates were then folded into the required shape needed using folding machine.

Rotating disc: The rotating disc was made from cast aluminium alloy, cut and machined to disc of 200 mm diameter. The disc (Figure 3) thereafter was drilled to a diameter of 20 mm with the use of a tailstock quill to enable proper fitting with the shaft.

Figure 3: (a, b) cast aluminium alloy rotating disc machined on the lathe disc

Frame: The material for the frame was cut into the required sizes based on the design of the polishing machine. After the cutting, the edges of the frame that were cut were then polished so as to remove the rough edges.

Shaft: The shaft material as obtained was a long cylindrical rod made of medium carbon steel. The rod was then machined into the shaft with the use of lathe machine.

Rotating belt: The rotating belt used had a diameter of 430 mm. V-belt was used because of durability and ease of installation. Another major advantage of V-belt is that its operation is calm.

Key: The key used was made of mild steel milled into appropriate size using milling machine. This was inserted between the shaft and the hub in other to prevent relative motion between them.

3. Assemblage and Test Running of the Machine

3.1 Assemblage of the machine components

For the fabrication, the manufacturing processes adopted are as follows:

i. **Cast and Machined Disc:** The machined disc, produced through sand casting of aluminium alloy was prepared ready for assemblage in accordance to the design.

ii. **Welding processes:** The steel frames and sheets were joined by welding and fastening screw.

iii. The rotating disc, the shaft and the pulley

In assembling the machine, the shaft was precisely positioned and fastened to the disc. The main shaft and bearings were installed in the bearing housing after which the polishing disc was mounted onto the shaft, and the motor connected to the shaft through the pulleys, belt and coupling.

iv. The frame and the cover plate

The frame (Figure 4) and the cover plate were assembled together by welding and other joining processes (bolt and nut) which involved the process of drilling the cover plate and the frame with a drill bit of 5 mm and then joined together with a screw of 5 mm diameter.

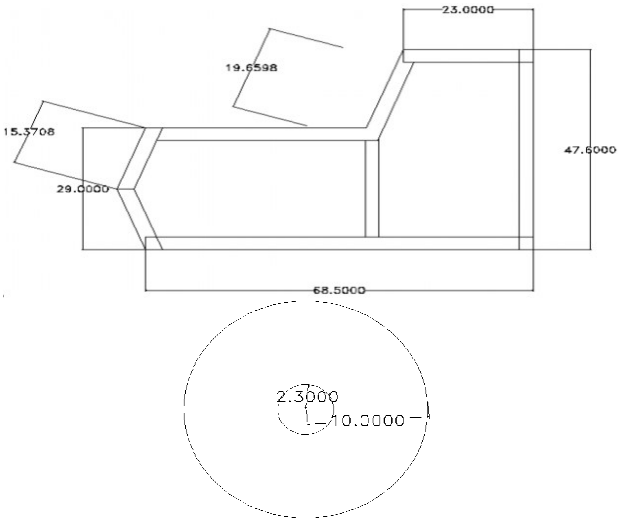
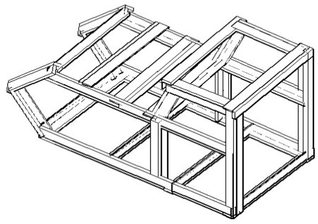


Figure 4: 2D design drawing of the body frame and rotating disc of the polishing machine

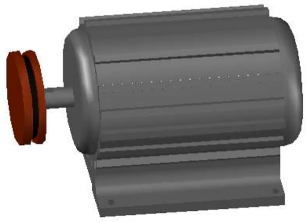
3D Design drawing of the various component of the laboratory polishing machine



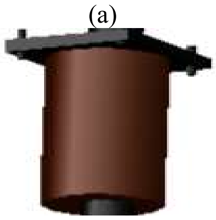
(a)

(b)

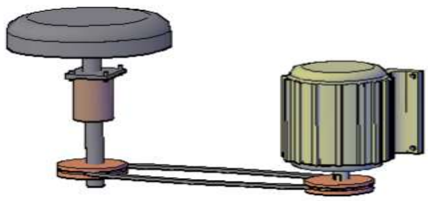
Figure 5: 3D design of the (a) framework assembly and (b) Rotating disc



(a)



(b)



(c)

Figure 6: 3D representation of (a) Electric Motor with a Pulley, (b) Shaft Housing with the Bearing and (c) the Motor, the Shaft, the Pulleys, the v-Belt and the Rotating disc assembly

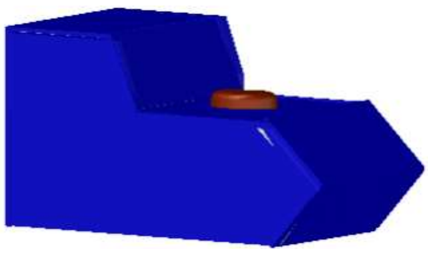


Figure 7: 3D design drawing of the laboratory polishing machine

The framework assembly and the final structure of the polishing machine are shown in Figures 8 and 9

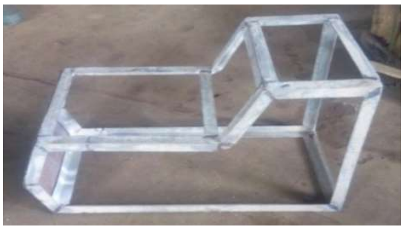


Figure 8: (a) steel angle bar framework

Figure 8:(b) with steel casing cover plate

a

b

Figure 9: The 3D views (a,b) of complete laboratory polishing machine

Table 2: Materials Selection

SN	Components	Specifications	Reason for selection
1.	Rotating disk	Aluminium alloy	Light weight, cast ability, machinability
2.	Steel framework	(37.5 x 37.5 x 3) mm thick mild steel angle bars	High strength, weld ability
3.	Steel casing	1.0 mm thick mild steel plate	High strength, weld ability
4.	Electric motor	IP44 BINS.CR; 1 HP; 0.75 KW, 220 V, 50 HZ, 1400 rev/min	High efficiency
5.	Ball bearing	Steel balls	Easy maintenance
6.	the Shaft rod	150 mm long x 3 mm thick mild steel rod	High strength,
7.	The shaft key	mild steel	Strong
8.	Pulley	Steel	High strength,
9.	v-Belt	High strength fiber	High strength
10.	Shaft Housing	Steel pipe	High strength, weld-able
11.	Speed regulator	High-low variable speed control	High efficiency
12.	Bolt and nuts	Steel	Low cost
13.	Rivet pins	Aluminium alloy	Low cost, not corrosive
14.	Damp proof rubber	Rubber	Reduce vibration and noise
15.	Plastic filler	Polymeric	Water resistance
16.	Painting	Gloss paint	Water resistance

Table 3: Cost of materials

SN	Components	Quantity	Rate	Amount (N)
1.	Rotating disk	1	15500	15500
2.	Steel framework	1unit	11700	11700
3.	Steel casing	1 plate	27500	27500
4.	Electric motor	1 Hp	45,800	45,800
5.	Ball bearing	2	2500	5000
6.	the Shaft rod	1	6000	6000
7.	Pulley	2	3500	7000
8.	V-belt	1	1800	1800
9.	Shaft Housing	1	4600	4600
10.	Speed regulator	1	25000	25000
11.	Bolt and nuts	20	120	2400
12.	Rivet pins	48	1200	1200
13.	Damp proof rubber	6	1200	7200
14.	Plastic filler	3.5 ltr	7500	7500
15.	Gloss paint	2 ltr	3250	6500
16.	Welding electrode	1 pk	5000	5000
	Total			**N179,700**

3.2 Test Running of Machine

Having fabricated the polishing machine, it was tested and evaluated in two (2) different modes: on load and without loading. It was also evaluated at different speed rate both with and without specimen for grinding and polishing.

The results obtained are as follows:

a. No specimen test:

During the 'no specimen test', the three speed was tested and the following observation were made.

i. The higher the speed, the higher the number of strokes and vice versa.

b. With specimen test:

When the specimen came in contact with the surface of the rotating disc at different speed interval, the following observation were made:

i. Each of the speed levels have important role to play in order to achieve good and smooth result for both grinding and polishing. For instance, the higher the speed, the faster it will take in grinding and polishing of the metal and the lower the speed, the more time it will take in grinding and polishing.

ii. The polishing machine proved to be effective for grinding and polishing of metallic materials during testing and evaluation.

c. Modification of driving motor

The initial TMP required 1.508kW i.e. 2.02hp was calculated to power a maximum total load of 1730g (consisting only a rotating Aluminum alloy disc and a work piece sample) which in practice produced much more and higher speed than it is required to operate the machine on manually handled 25 – 30g work specimen. Therefore, a motor of lower capacity 0.75kw (1hp) was used as a replacement for the 2.02hp considering efficiency of polishing and safety of the operator. However, the 2.02hp motor designed may still be retained in cases where the rotating disc is made from (i) heavy or higher density materials (such as stainless steels and cast iron) than aluminium alloy. (ii) of bigger rotating disc diameter while (iii) multiple work sample are involved, which is different from the current situation

4. Conclusion

The portable, vibration-free and easy to operate grinding and polishing machine has been designed and fabricated with selected materials locally sourced based on consideration for the cost and availability. The work has shown that the machine is economical to fabricate. Hence, the problem of importing laboratory polishing machine in Nigeria can be minimised as it provides excellent results when compare with imported one.

The performance evaluation of the laboratory polishing machine showed that objectives of the work was achieved, that is, the design and fabrication of a grinding and polishing machine that can prepare metals for physical metallographic examination and characterisation determination.

Based on the test-running and assessment carried out at different speeds, grits of abrasive papers and on variety of materials (metal alloys, composites, plastic, ceramics) for both dry and wet operating conditions, the results show that it is efficient and simple to maintain. It is therefore recommended for laboratory use in higher institutions in order to solve the problem of its unavailability for students' practical purposes.

It is recommend that future development of the machine should consider increasing the number of speed variations and inclusion of multiple sample holder

Acknowledgements

The authors acknowledge the management of Premier Wings Engineering Services Ado-Ekiti for providing the workshop and also, the electronic laboratory unit of Obasanjo Innovation Center, Federal Polytechnic, Ado-Ekiti for supporting the research work

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