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DEVELOPMENT AND EVALUATION OF A DRILL RE-GRINDING FIXTURE

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ABSTRACT
Generally, manual method of re-grinding drills poses the dangers of damage and accidents. This paper reports the method used in the design, fabrication and testing of the drill re-grinding fixture. The fabricated fixture can withstand maximum normal and tangential forces of 121.34 N and 87.76 N respectively. The developed fixture shows it is suitable as work holding device for re-grinding drills bits with diameter of at least 4.5 mm and above without breakage and difficulty. The average time for complete re-grinding is about six minutes (loading and unloading time inclusive) and no injuries were recorded. The grinded surfaces conform to the standard tool geometry for a twist drill. Hence, the use of this drill re-grinding fixture in the engineering workshops obviates the rigor of manual handling of drills during grinding.

Keywords: *design, evaluation, drill, fixture, grinding, cost.*

1. INTRODUCTION

Drills are multi-point cutting tools usually made from high speed steels and used to produce round holes in work-piece. There are different drills but the most common drill used is the twist drill. They are provided with double helical flutes called twist. The twist could be quick or slow. The cutting action is done via two main cutting edges and chisel edge. This depends on the rake angle and clearance angle. Other important parts of the drill are: the web (for strength), land (creates the body clearance), shank (to prevent rubbing during cutting action) to mention but few. During drilling, drills become dull by buckling and bending action. They must be re-sharpened before it can be used for drilling again. The major means of re-sharpening a dull drill bit is by grinding either manually or on double ended grinding machine called pedestal grinder [1]. With observations from the workshop, the manual method is not recommended due to certain limitations such as: lips of unequal lengths to the centre, lips of unequal angle to the centre, incorrect clearance angle, incorrect point angle, and lips of unequal lengths and unequal angle to the centre. The method of re-sharpening the drill with the aid of drill re-grinding fixture should eliminate some, if not all, problems associated with manual grinding.

Grinding is very similar to other metal cutting operations and can be described as a multi-tooth operation in which a number of abrasive grains held by a bonding material perform the cutting operation [2]. It is well known that grinding force is one of the most important parameters in evaluating the whole process of grinding. It is reported that grinding forces are composed of chip formation, rubbing and ploughing forces [3]. The grinding force is resolved into three component forces namely: normal grinding force (F_z), tangential grinding force (F_x) and a component force acting along the direction of longitudinal feed which is usually neglected because of its irrelevance. The normal grinding force, F_z has an influence upon the surface deformation and roughness of the work-piece while the tangential grinding force, F_x mainly affects the power consumption and service life of the grinding wheel [4]. The concept of contact mechanics further gives an insight into the cutting action of the abrasive wheel.The grinding process is the sum of the interactions among the wheel topology, process kinematics, and the work-piece properties [5]. At the very first stage of the interaction between abrasive grit and the work-piece, plastic deformation occurs as a result of increase in temperature of the work-piece and cause normal stress to exceed yield stress of the material. After a certain point, abrasive grit penetrates into the material and displaces it. This is responsible for the ploughing forces. Finally, the grit starts shearing action and removes the chip from work-piece [6, 7]. The quality of the surface finish depends on selecting the correct grinding wheel. They are embedded in a matrix called bond. The factors that determines the selection of a suitable wheel are: the nature of the abrasive, grain size, grade of the bond, wheel structure and nature of bond [8].

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A fixture is a machine shop device that holds the work piece so that the hands of the operator are free. The factors responsible for a good design of fixture are location, clamping, clearance, rigidity and handling [9]. The first patented drill sharpening attachment for grinding machines was invented by Rodgers in United States [10]. Many inventors such as Mallory, Sawyer to mention but few took part in the development of grinding attachment until 1914 when Wincrantz invented twist drill grinding attachment [11]. Chavan *et al.* reported the fabrication of a grinding attachment for lathe in 2015 [12].The limitation of the existing design includes accommodation for specific range of size, two degree of freedom during re-grinding and requirement of special stand for mounting the attachment. Due to the problems encountered with manual grinding of drills on pedestal grinder, there is a need to develop a grinding fixture locally in Nigeria. The cost of available fixture, with importation charges, ranges from 25-35 British pounds. So, a fixture with less than 15 British pounds is required so as to make it affordable for its users. The objective of this research is to design a grinding fixture to replace the manual method. Adequate knowledge in the design of jigs and fixture was applied in terms of loading, stability and rigidity. The developed fixture will have four degree of freedom for efficient tool grinding, accommodate wide range of sizes because of its vee-shape support and a stand along with the fixture. Then, literatures were reviewed with reference to journals, thesis, design handbooks to mention but few.

2. MATERIALS AND METHODS

2.1 Equipment Description

The component parts are briefly discussed below:

i. ***Tool holder and locator:*** This consists of a vee groove with an overhead at the front part. The angle of the vee groove is about 70^0. The overhead is 5.27mm away from the front end and it is a U-channel welded to the vee groove. The length and height of the vee-groove are 21.9mm and 3.6mm respectively. Threaded through hole is drilled at the centre of the overhead so as to accommodate the hold-down bolt. The support base is welded to it underneath. It is made of mild steel.

ii. ***Support base:*** It connects the tool holder and the pivot rod. It is a metallic cuboid with dimensions of 30 x 16.63 x 20.91mm. A flat bar, of both flat and rounded end, is welded to the support base. A hole of diameter 11mm is drilled at the rounded end. This hole accommodates the pivot bolt. The pivot bolt holds the tool holder in correct angle against the wheel. It is made of mild steel.

iii. ***Pivot rod:*** It plays major role during grinding. There is a mark on it that corresponds to the mark on the support rod. Once the mark rotates through 59^0, the required lip angle is generated. It is a solid rod of diameter 57.9mm and length of 79.54mm. At the upper end of the rod, a flat bar of rounded and flat end is welded to it. A hole of diameter 11mm is drilled at the rounded end. This hole accommodates the pivot bolt. At the lower end of the rod, there is a step turning of length of 60mm. It is made of mild steel.

iv. ***Support rod:*** This rod plays a vital role in the grinding. There are 2 marks on it to ensure that the required 59^0 of turning the drill is ensured. It is a solid rod of diameter 11mm and length of 60mm. A hole drilled on the upper part of this rod accommodates the step turning on the pivot rod. This combination provides the rotation of the pivot rod about 360^0. Another hole is drilled by the side of diameter 11mm. This hole accommodates the locking bolt. It is made of mild steel.

v. ***Base bracket:*** It is approximately of L-shaped steel box. The support rod is welded to its top while is rigidly attached to the concrete base by bolts of diameter 10mm.

vi. ***Concrete base:*** It supports the entire re-grinding fixture. It is made of concrete and reinforced steel rods. The base is a cuboid of dimensions 360 x 360 x 400mm

Figure 1: Assembled fixture

2.2 Design Consideration

The factors considered in the design of the re-grinding fixture are grinding force required to sharpen the drill, materials and geometry of the fixture components, sizes of the drill to be sharpened, stability and rigidity and space availability.

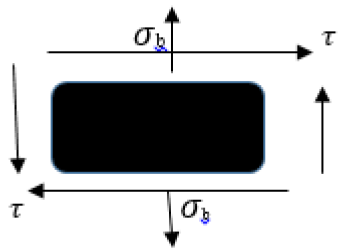


Figure 2: Stress element of the bolt

2.2.1. Determination of Grinding Force

The power required to re-grind the drill is determined as follows:

$$Power = F_s \; x \; MRR \quad (1)$$

Where F_s is the specific cutting force in N/m^2 and MRR is the metal removal rate in m^3/secs.

with $F_{s\,min}$ = 50,000N/mm^2[13]and P= 4kW, then MRR = 80mm^3/s

Normal and tangential forces [14]are computed as:

$$F_Z = 4.13MRR^{0.77} + 0.74 \quad (2)$$

$$F_X = 2.51MRR^{0.81} + 0.43 \quad (3)$$

By substituting the value of MRR, the forces are calculated to be: F_z=121.335N and F_x = 87.763N

2.2.2 Determination of the Size of the Pivot Bolt

The pivot bolt is subjected to bending, torsional and shear stresses as seen from the geometry of this fixture. The stresses are computed as:

The bending stress on the pivot bolt, σ;

$$\sigma = \frac{My}{I} \quad (4)$$

where centroid of the pivot rod, $y = \frac{diameter}{2} = \frac{0.06}{2} =$ 0.03m

Moment, M = force (F_Z)x distance = 121.335x0.198 = 24.02 Nm

Moment of inertia, $I = \pi\frac{d^4}{64} = 6.36255x10^{-7}\ m^4$.

where d is the diameter

By substitution of values, σ = 1.1327MPa

The torsional stress on the pivot bolt, $\tau_{t;}$

$$\tau_t = \frac{Td}{2J} \quad (5)$$

where d is the diameter as defined above.

torque, T = Force (F_X)x distance = 87.763x0.198 = 17.3771 Nm

Polar moment of inertia, $J = \frac{\pi d^4}{32} = 1.27251x10^{-6}$m^4.

where d = 0.06m as defined before.

By substituting the values, τ_t= 0.4097MPa

The shear stress on the pivot bolt, $\tau_{v;}$

$$\tau_v = \frac{4v}{3A} \quad (6)$$

where v= 121.335N (shear force) and area, A =2.8278x10^{-3} m^2, τ_v = 0.0572MPa

Therefore, Tensile stress,$\sigma = 1.1327\ MPa$

Shear stress,$\tau = \tau_t + \tau_v$ = (0.0572 + 0.4097)MPa = 0.4669 MPa

To calculate the principal stresses $(\sigma_{1,2,3})$ on the pivot bolt, the analysis is given below:

$$\sigma_{1,3} = \frac{\sigma_x + \sigma_y}{2} + \left(\left(\frac{\sigma_x - \sigma_y}{2}\right)^2 + \tau_{xy}{}^2\right)^{1/2} \quad (7)$$

In (7) σ_x is the plane stress along the horizontal axis, σ_y is the plane stress along the horizontal axis and $\tau_{xy}$is the shear stress in the bolt, σ_1 is the maximum normal stress on the bolt and σ_3 is the minimum normal stress on the bolt.

Since $\sigma_x = 0$, the equation above reduces; $\sigma_{1,3} = \frac{\sigma_B}{2} + \left(\frac{\sigma_B{}^2}{2} + \tau_{xy}{}^2\right)^{1/2}$

σ_B is the bending stress calculated in equation 4. By substituting, hence, σ_1 = 1.3003MPa, σ_2 = 0 MPa, and σ_3 = - 0.1676MPa. By using Von Mises criterion to design against failure, the yield stress, s_y is as given by [15, 16]:

$$s_y = \sqrt[2]{\frac{((\sigma_1 - \sigma_2)^2) + ((\sigma_2 - \sigma_3)^2) + ((\sigma_1 - \sigma_3)^2)}{2}} \quad (8)$$

By substituting the values of principal stresses into equation 8, s_y= 1.3917MPa

The maximum shearing stress (τ_{max}) is obtained from the expression:

$$\tau_{max} = \frac{\sigma_1 - \sigma_3}{2} \quad (9)$$

By substituting the principal stresses, τ_{max}= 0.7340MPa

The shearing force, $P_s = \left(F_z{}^2 + F_x{}^2\right)^{0.5}$

=$(121.355^2 + 87.763^2)^{0.5}$= 149.748N,

The specification of the pivot bolt is determined from the equation10 and 11 below:

$$P_s = \pi \times n \times \frac{d_c{}^2}{4} \times \tau_s \quad (10)$$

Substituting n = 1, P_s= 149.748N and τ_{max} = 0.7340 MPa into equation 10. Then, the standard core diameter, d_c = 16.12 mm.

Hence, M14x2 bolt can be used as coarse type or M14x1.5 for fine type.

$$P_b = \pi \times \frac{d_c{}^2}{4} \times \sigma_t \quad (11)$$

Here P_b is the bending force. By substituting P_b = F_x = 121.335N, andσ_t= 1.3917MPa. Then, the standard core diameter, d_c= 10.5353mm

Hence, M20x2.5 for coarse series and M18 x 1.5 for fine series. Finally, a M20 bolt made from steel is selected for the pivot bolt.

2.2.3 Determination of the Size of the Drill Clamp Bolt

The maximum gripping force by human hand is 400N [17]. Since the fixture should be easily operated, the bolt parameters can be suitably determined from equation below [18]:

$$p_u = \mathrm{wtan}(\phi_s + \theta) \quad (12)$$

where p_u is the applied force to turn the bolt = 20N (arbitrarily taken) and w is the grinding force that causes slippage of the drill, $F_z = 121.335N$. By substitution, $\phi_s + \theta = 9.36^0$. Recall, $\tan\theta = \frac{lead}{2\pi r}$ and $\tan\emptyset_s = \mu_s$.

Taken coefficient of friction (μ_s) to be approximately 0.1641for metal to metal contact. The bolt parameters are selected to suit the design specification such that it is self-locking ($\emptyset_s > \theta$). Then, a standard bolt of M11x 1.5mm.

2.2.4 Determination of the Size of the Locking Bolt

This bolt is used to prevent the horizontal turning of the pivot bar after re-grinding. The bolt parameter are obtained as computed in equation 12. So, a bolt of M11x1.5mm is selected.

2.2.5 Determination of the Buckling Load

The recommended value for the effective length:

$$l_{eff} = 0.65l \quad (14)$$

Here *l* is the length in metres. The support bar is a fixed-fixed member. Slenderness ratio,

$$S_r = \frac{l_{eff}}{k} \quad (15)$$

where k is the radius of gyration in metres.

Upon analysing the fixture, the total length of the support and pivot rod is 15.2mm.Then, $S_r = 0.659$

The critical slenderness ratio, S_{rc};

$$S_{rc} = \pi\sqrt{\frac{2E}{\sigma_{yc}}} \quad (16)$$

Here E = 210GPa (for mild steel), σ_{yc}= 220MPa (for mild steel as in [19, 20]). Then, S_{rc}= 137.28

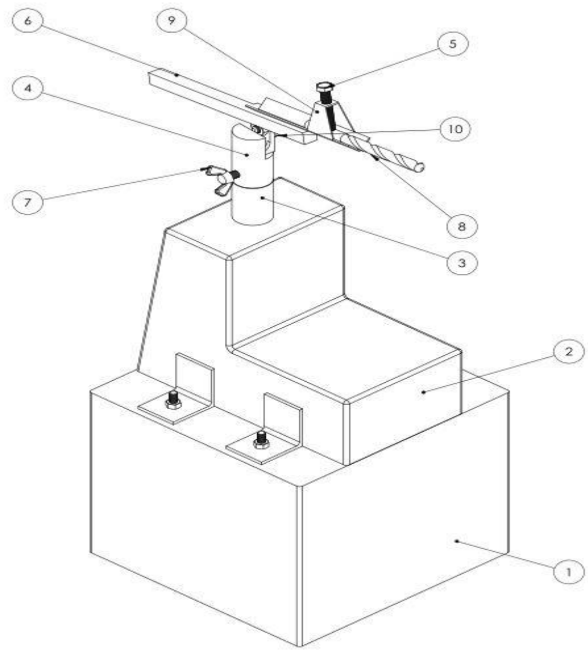
Since $S_r < S_{rc}$, then Johnson formula, is used to determine the critical load [21]:

$$F_{cr} = S_y A \left(1 - s_y \frac{(s_r)^2}{4cE\pi^2}\right) \quad (17)$$

In (17) c = 4 (fixed-fixed end conditions), $yield\ stress, s_y = \sigma_y$, A = cross sectional area of the pivot rod, F_{cr} = critical load, S_r= slenderness ratio and substituting these parameters into equation 17, the critical force is 0.58MN. Taken a factor of safety of 1.5, the safe load is 0.39MN. By using this value, the mass of the clamp should not be greater than 38,622kg to guard against buckling of the support and pivot rod.

2.3 Fabrication Processes

Fabrication of the re-grinding fixture was carried out in the fabrication workshop, Department of Mechanical Engineering, Federal Polytechnic, Ado-Ekiti, Ekiti State. The basic manufacturing processes which include cutting, shaping, welding, and other joining processes were undertaken.



Item	Part Name	Qty	Material	Description
1	Concrete base	1	Concrete	360 x 360 x 400
2	Base bracket	1	Mild steel	L-shaped box
3	Support rod	1	Mild steel	ϕ57.9x 7
4	Pivot rod	1	Mild steel	ϕ57.9 x 8.6
5	Drill clamp bolt	1	Steel	M11x1.5
6	Support base	1	Mild steel	30 x 16.63 x 20.91
7	Locking bolt	1	Steel	M11x1.5
8	Tool locator	1	Mild steel	V-groove of 70^0 , *l* = 219
9	Tool holder	1	Mild steel	U-channel
10	Pivot bolt	1	steel	M20

Figure 3: The part list and isometric view of the fixture

2.4 Operation of the Fixture

The basic procedure of operation is highlighted below:

i. Loose the locking bolt and pivot bolt so as to be able to set correct position of the drill.
ii. Unscrew the hold-down bolt and insert the drill bit appropriately against the grinding wheel.
iii. Tighten the hold-down bolt to hold the drill firmly.
iv. Then, the pivot bolt is tighten to set the drill at the appropriate angle.
v. Switch on the grinder to commence grinding. During operation, the drill is moved into the grinding wheel through a small angle of 59^0 until the required tool geometry is generated.
vi. Move the clamp unit away, loose the hold-down bolt to turn the drill, tighten the hold-down bolt and continue re-grinding until it is completed.
vii. Move the clamp unit away from the grinding wheel, loose the hold-down to remove the drill bit and lock-up the pivot rod by tightening the locking bolt.

2.5 Performance Testing

The fixture was evaluated in comparison to manual grinding using pedestal grinder. Drill bits of different sizes were placed in the fixture to ascertain the drill sizes that the fixture can suitably hold and re-grind. Then, ten different drill bits were randomly picked and labelled in two categories A and B. Category A were manually re-grinded while category B were fixture - supportedly re-grinded. There were five samples under each category and re-grinding test was carried-out. The evaluation was based on the tool geometry formed, accuracy, record of accident and time taken. The tool geometry formed is examined to ensure that the twist and web are not destroyed during re-grinding including the rake and clearance angle. Also, there should not be excess chip removal. The accuracy is based on uniformity of the clearance and cutting edge. Any occurrence of accident was noted and stop watch was used to record the time taken to complete re-grinding.

3. RESULTS AND DISCUSSIONS

The Figures 4 to 7 show the physical appearance of the geometry of re-grinded drills. Figure 4 describes the lip length of re-grinded drill using the grinding fixture. It is observed that the right chisel face is the same with the left face. Figure 5 describes the lip length of re-grinded drill using the manual method. By physical observation, right chisel face is bigger than the left face. This implies that that the lip angle is not 120^0.Though the observed shapes seems similar for both methods of re-grinding but there are irregularities with the manual re-grinding. This is in the sense that there is unequal lip length, non-uniform rake angle and clearance across the cutting edge. Figure 6 presents the position of the chisel edge/lip for a re-grinded drill using grinding fixture. It is seen that the chisel edge is centered and uniform. Figure 7 presents the position of the chisel edge/lip for a re-grinded drill using manual method. It is seen that the chisel edge is not centred as it offsets from the centre to the left. So, this confirms problems associated with manual re-grinding and suitability of the fixture-supported regrinding.

The result of re-grinding tests using both the manual and fixture-supported methods are presented in Table 1. From five tests randomly conducted, the time taken to re-grind drills using manual and grinding fixture were noted. Also, occurrence of injury accidents were recorded to ensure that the objectives of this research is fulfilled.

Table 2 shows the summary of the sizes of the drill bit that the fixture can re-grind with ease and firmly. Then, Table 3 was prepared by measuring the lip angle, and carefully examine the chisel edge of the randomly selected drills. The assessment is to test the conformity of the produced shapes to a standard drill in terms of accuracy of the tool geometry. The standard lip angle is 118^0. Therefore, any deviation beyond the value of 118.0 ± 5 is classified as medium or low.

Figure 4: Plan of fixture-supported grinded drill

Figure 5: Plan of manually grinded drill

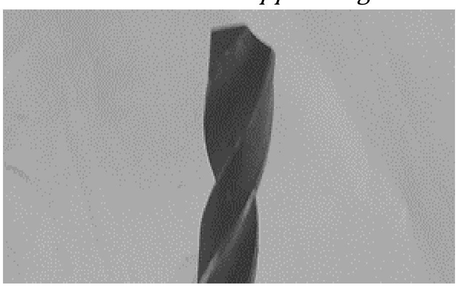


Figure 6: Side view of fixture-supported grinded drill

Figure 7: Side view of manually grinded drill

Table 1: Results of re-grinding test using manual and fixture-supported methods

Test	Fixture Supported Re-Grinding				Manual Grinding	
	Loading Time (Sec.)	Grinding Time (Min.)	Unloading Time (Sec.)	Record of Accident	Grinding Time (Min.)	Record of Injury
I	26.16	3.59	12.55	No	3.50	No
II	29.02	5.12	6.16	No	5.15	Yes
III	15.34	5.49	5.58	No	5.50	No
IV	21.43	4.00	6.56	No	5.00	No
V	11.09	6.08	8.26	No	6.00	Yes

The time required to complete re-grinding on the fixture based on the samples subjected to grinding is 5.5$\pm$0.4 minutes. The average time for manual re-grinding is 5.18 minutes. The total time taken for the fixture-supported re-grinding is longer than the manual method due to loading and unloading of the drill bit. This is in terms of loading, unloading and loosening and tightening of the hold-down bolt during the operation. Also, the assembly of fixture parts protects the operator from accidents by using drill grinding attachment. Most especially damage to the hand due to the grinding wheel. Finally, the drill sizes of 4.5mm and above can be used on fixture without any difficulty.

Table 2: Summary of the drill bit sizes that the fixture can hold firmly

Drills diameters(mm)	Measure of Fixture Holding
Below 4.5	Not held
4.5 and above	Firmly held

Table 3: Results of the level of accuracy of the tool geometry

Test	Fixture Supported Re-Grinding		Manual Re-grinding	
	Lip angle (degrees)	Accuracy	Lip angle (degrees)	Accuracy
I	118	High	100	Medium
II	118	High	94	Low
III	118	High	86	Low
IV	118	High	105	Medium
V	118	High	140	Low

4. CONCLUSION

A fixture for re-grinding drill bits has been designed, fabricated and tested in this study. A preliminary evaluation of the fixture in terms of time, accuracy, occurrence of accident indicates that it has a high potential in substituting the manual method of re-grinding used drill bits. Hence, the non-uniform grinding and accidents associated with manual holding of the drill while grinding is eliminated.Hence, it is recommended for use.

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