Design of a Rotary Blade Glass Pulverizing Machine

Alexander Osayimwense Osadolor[1], Bashir M. E[2], Osifo T. I[3], Ehi-Eromosele F[4]
Department of Mechanical Engineering, University of Benin, Nigeria

Abstract

Glass waste can be recycled which behooves the engineer as part of the ingredient for making glass and also used extensively for the production of useful products such as paint, abrasives, AstroTurf and other ceramic wares etc. Recycling of glass may involve the crushing of the glass into desired particle sizes with the use of safe and efficient pulverizing machines. This research work focuses on the design of a glass pulverizing machine which has a drop loading hopper with a retractable cover to prevent particle escaping the chamber, a horizontally oriented steel shaft to which is attached 3 steel blades separated at 120^0 to their centre, all enclosed in a cylindrical crushing chamber with perforations of predetermined sizes that allows the passage of pulverized glass particles through it and a 1hp high speed motor which drives the shaft. The shaft-blade assembly was separated from the internal walls of the cylindrical crushing chamber by a clearance of 10mm to enhance crushing to finer particles and forced passage of the glass particles through the perforations. The drop loading of glass through the hopper from above reduced the crushing force of the blades, energy usage of the machine and ensured retraction of the glass particles. Results from the testing of the machine showed that fine glass particles as small as 20μm were obtained and the glass crushing capacity was 230kg/h.

Keywords: Crush; horizontal-shaft; production; recycle; waste

1. Introduction

Glass is an amorphous substance having sand, lime and soda as its major constituents. It has found applications as a raw material in the production or processing of other materials such as paint, abrasives, Astro-Turf, ceramic wares, and other glass products etc owing to a growing population an industrialization around the world, there has been a consequential increase in the production and demand for glass products which turn out to become wastes after utilization and constitute unwanted and environmental degrading materials. Glass wastes falls into a class of non-biodegradable solid waste making it not to decompose, Naveenbala et al (2017). However; glass waste can be recycled for the production of various other materials. In many developing countries like Nigeria for example, its municipal waste is usually made up of bottles, broken glass ware, light bubbles and other items made of glass, yet many cities in these developing countries spend 20-50% of their environmental budget on solid waste management and only 20-80% of the waste is collected, an indication that the standard of waste management is very poor with poor documentation of waste generation rates, inefficient storage, collection system, and under-utilization of disposal sites, Kadafa et al (2012). The recycling of waste glass has therefore become a reliable means of converting waste glass into useful products. Glass recycling uses less energy than manufacturing it from the raw materials (sand, lime and soda). Every metric ton of waste glass recycled into new items saves about 315 additional kilogram of carbon dioxide from being released into the atmosphere as obtained during the manufacturing of new glass GRIS (2006). Glass can be recycled a million times over to produce bottles and jars of the same high quality every time which translate to converting waste to wealth leading to zero waste Ogunro et al, (2018).

Recycling of glass may involve the crushing of the glass into desired particle sizes with the use of hammer mills and pulverizer. While hammer mills fracture and reduces the glass into cullets of smaller sizes, the pulverizers are better off with the grinding of the cullets into powdered or smaller grains cullets. Modern size reduction equipment (i.e. Hammer mill and Pulveriser) was designed and manufactured to serve a singular function (Kakahy et al., 2001; Nasir 2005; Sanni et. al., 2008; Aderemi et al., 2009; Nwaigwe et al., 2012). They either crush bulk material to grain (Hammer mills) or pulverise grain to powder (Pulverisers). Orhorhoro et al, (2017) designed a hammer mill for crushing of Glass and agricultural solid waste. The focus of the researchers was on the machine components optimization with no particular mention of the output glass particles (cullets sizing). Ogedengbe and Abadariki, (2014) developed and evaluated the performance of a bone-milling cum pulverising Machine The machine consists of a hopper, a milling chamber with hammers assembly, a pulverising chamber with two abrasive surfaces, a screw feeder, belts and pulleys, hammer mill-shaft, pulveriser shaft as well as an electric motor for power transmission. The design concept integrated the milling and pulverising of animal bones into one machine. Animal bones are milled to a maximum size of about 12mm in the milling unit and then delivered through an auger to the pulverising unit. Xuan et al (2012) Develop on a hammer mill with Separate sieving device. The aim of their design was to mitigate errors in particle sizing arising from the so-called material-circulation layer which is formed between the rotor and screen in which the most coarse grain are distributed at the outer of the circulation layer against sieve because of the centrifugal effect, which blocks the holes of the sieve, resulting in the fine product located at inner layer not being able to go through the screen even when the proper size is reached, this part of material will be ground again and again, leading to the problems of high energy consumption, material over milled at elevated temperature. The over fine glass particle output is not good for some poultry and animals and the hot product easily deteriorate and difficult to store Jindal and Austin [(1976); Islam and Matzen (1988); Gotsis C et al. (1985); Petya et al, (2011)]. This research work focuses on the design of a glass pulverizing machine which is aimed at mitigating some setbacks encountered in many small-scale glass pulverizers. Main focus in the present glass pulverizer design is to reduce or eliminate material recirculation blockade through a good machine configuration, make the machine compact and simple without creating separate sections for pulverization and sieving and finally to reduce energy consumption through optimized glass pulverization by creating a drop loading hopper to increase glass fracture impact and reduce load on the hammers during operation.

2. Methods

The machine design considerations include the followings;

i. Proper sieve designs a spacing from hammer to reduce material recirculation blockade
ii. Simplicity and weight reduction through a compact design integrating the pulverizing and sieving section into a unit
iii. Reduction in energy utilization through optimized hopper design that can enable horizontal roll and vertical drop down feeding of the glass thereby increasing the fracture impact and reducing load on the hammer
iv. Elimination of rebound of culets after impact by incorporating a retractable cover at the feed hopper
v. Suitability for medium and small-scale glass recycling for manufacture of other products
vi. Use of locally sourced materials with adequate material properties and strength

The machine design consists of a hopper; which has a one-way flap to prevent escape of glass particles, a crushing chamber, an electric motor, frame, shaft, three steel blades or hammers, ball bearings, output product collector, v-belt and pulley system. Its operation is such that as the whole or pieces of glass material waste is fed in through the hopper, it rolls through a horizontal distance before falling under gravity through the vertical hopper into a rotating shaft carrying three metal blades. On impact with the running blades, the kinetic energy of the falling glass is converted into potential energy on impact and shatters before the rotating blades starts to drag along and fling the fractured glass materials against the walls of the hard sieving chamber due to the distance between the blades and the hard wall. This enables considerable pulverizing of the glass before the bulk culets build up enough to be dragged against the wall of the sieving chamber and they pass through the sieve holes with ease allowing incoming glass culets to go through the repeated process. The motor transfers rotary torque to the shaft via belt and pulley system.

2.1 DETAIL DESIGN

Power Required for the machine

$$\frac{P}{\dot{m}} = w_i\left(\frac{10}{\sqrt{D_{pb}}} - \frac{10}{\sqrt{D_{pa}}}\right) \quad (1)$$

Where P is the Power required for crushing

$\dot{m}$ is the mass crushed

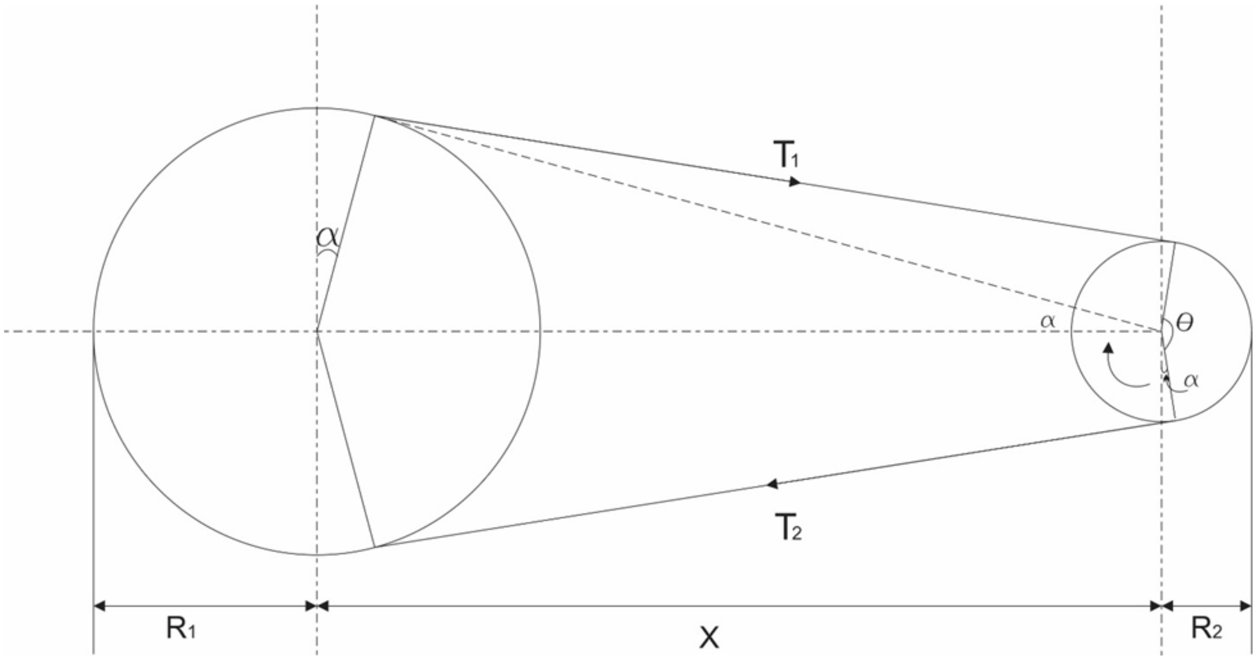
w_i is the Bond's work index

D_{pb} is the particle size diameter of product

D_{pa} is the particle size diameter of feed

Belt Design

Figure 1: Belt and Pulley System



Cross section area (A_c) of type *A* belt is the area of a trapezium

$$T_{m1} = \sigma \times A_c \quad (2)$$

$$\ln\left(\frac{T_{m1}}{T_{m2}}\right) = \mu\theta \operatorname{cosec}\beta \quad (3)$$

$$\theta = (180° - 2\alpha).\frac{\pi}{180} \quad (4)$$

Where:

T_{m1} is the maximum tension in the tight side;

T_{m2} is the corresponding maximum tension in slack side;

μ is the coefficient of friction;

θ is the angle of lap in *radians*;

β is half groove angle;

α is the angle a normal at the point of tangency (of the belt and either of the pulleys) makes with the vertical.

$$\sin\alpha = \frac{(d_1 - d_2)}{2x} \quad (5)$$

where *x* is the pulleys center-center distance,

Design tensions (T_1 and T_2) in belt are given by;

$$\ln\left(\frac{T_1}{T_2}\right) = \mu\theta cosec\beta \quad (6)$$

Where:

T_1 is the tension in the tight side;

T_2 is the tension in the slack side;

$$L = \frac{\pi(d_1+d_2)}{2} + 2x + \frac{(d_1-d_2)^2}{4x} \quad (7)$$

Shaft Design

Fig 2: Front and Side view of shaft and blade system

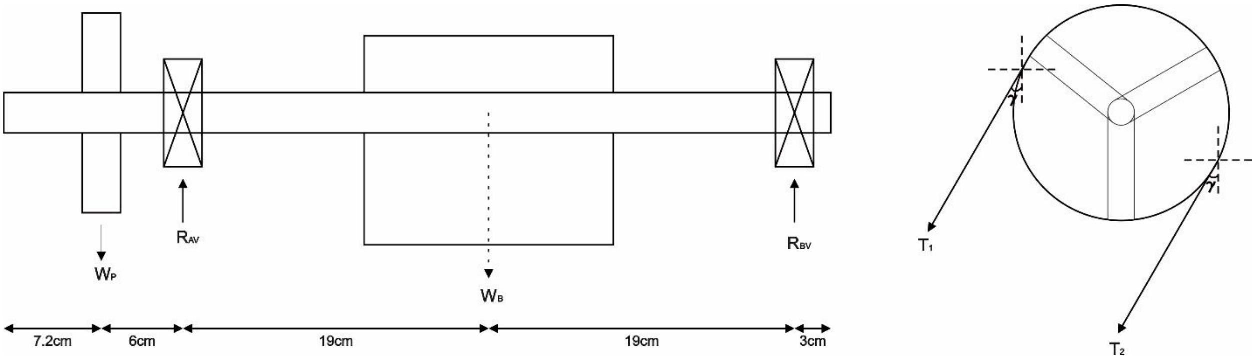
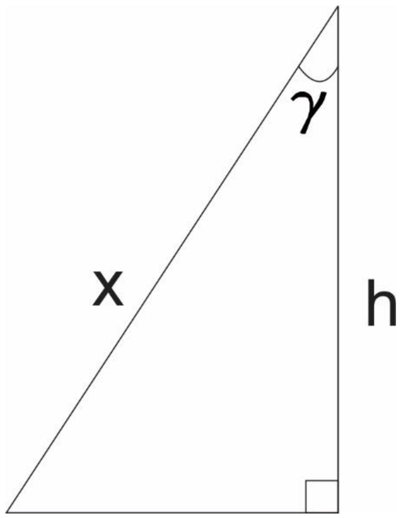
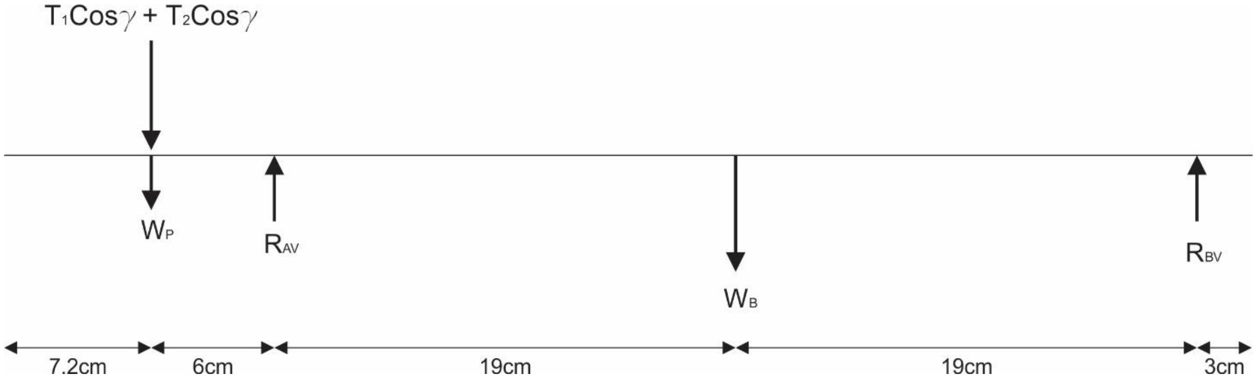


Figure 3: Pulley Centre-Line Triangle



Solving for R_{AV} and R_{BV}; $\sum F_V = 0$;

Figure 4: Free body diagram of vertical forces on shaft



$$W_p + W_b + T_1 \cos\gamma + T_2 \cos\gamma = R_{AV} + R_{BV} \quad (8)$$

17.66+116.25+109.218cos 23.556+3.741cos 23.556 = R_{AV}+R_{BV}

∴ R_{AV}+R_{BV} = 237.46

$\sum M_V$ = 0; taking moment about R_{BV};

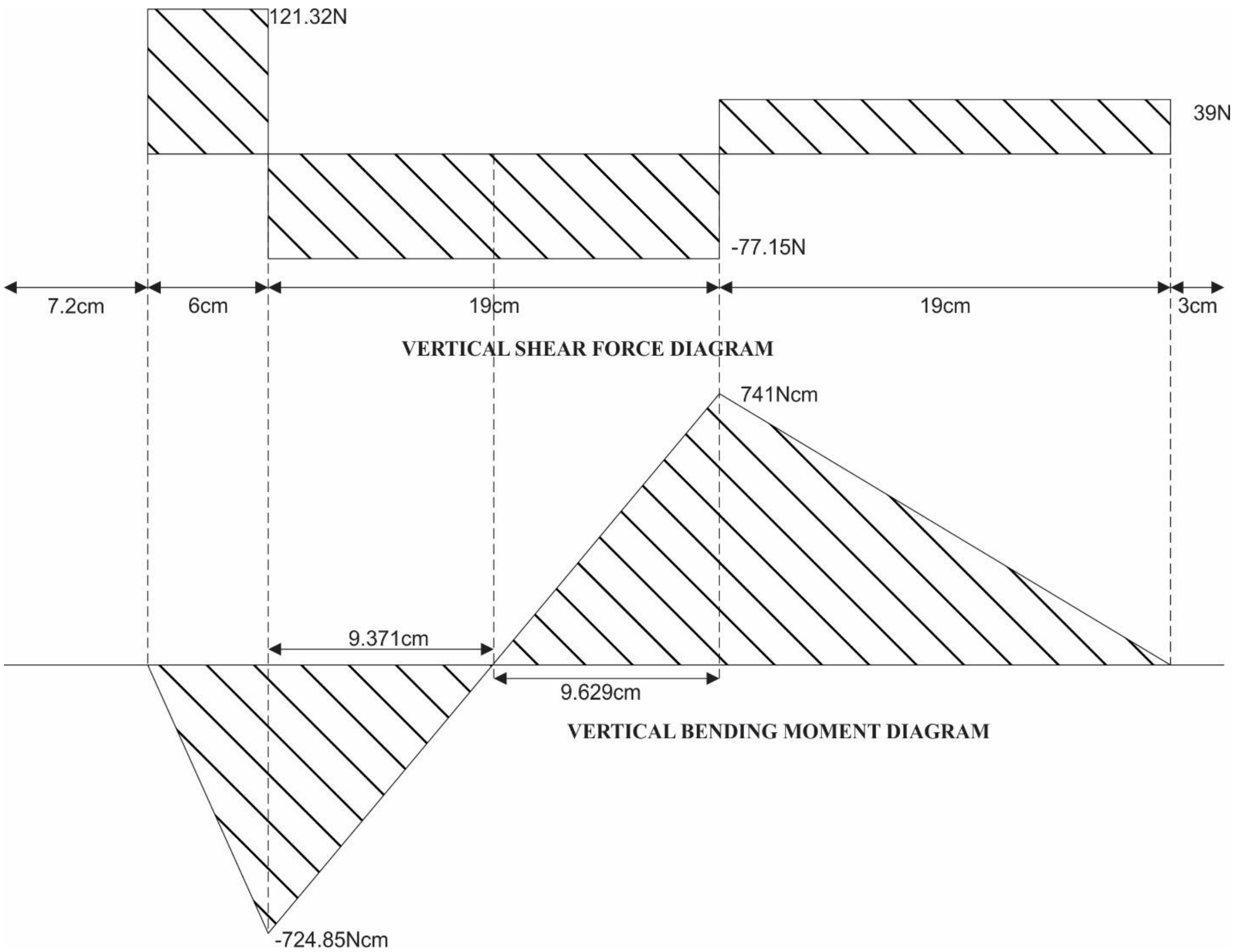
W_b×19 + $(W_p + T_1 \cos\gamma + T_2 \cos\gamma) \times 44 = 38R_{AV}$

(116.25×19) + (17.66+ 109.218cos 23.556 + 3.741 cos 23.556) $\times 44 = 38R_{AV}$

∴ R_{AV} = 198.47N ∴ R_{BV}= 237.46 − R_{AV} = 39N

Shear Force and bending moment diagram for vertical forces gives;

Figure 5 : Vertical Shear Force and Bending Moment Diagram



Solving for R_{AH} and R_{BH}; $\sum F_H = 0$

Figure 6 : Vertical Shear Force and Bending Moment Diagram

$$T_1 \sin\gamma + T_2 \sin\gamma = R_{AH} + R_{BH} \tag{9}$$

$109.218 \sin 23.556 + 3.741 \sin 23.556 = R_{AH} + R_{BH}$

$R_{AH} + R_{BH} = 45.14$

$\sum M_H = 0$; taking moment about R_{BH};

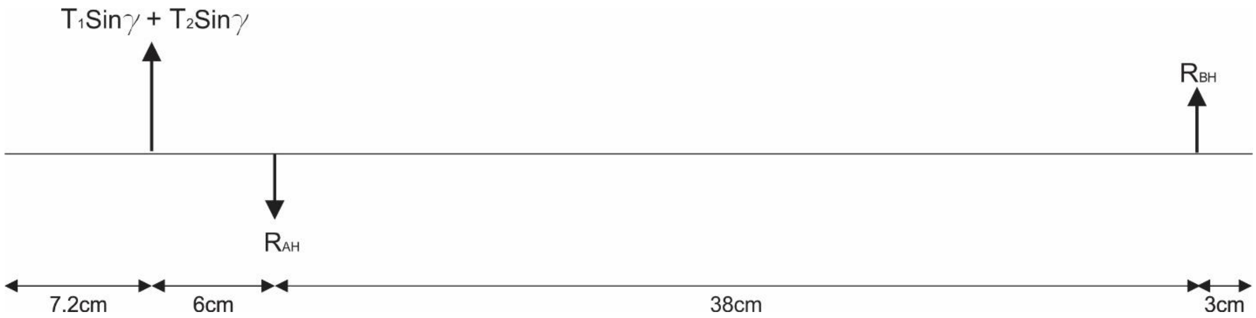
$(T_1 \sin\gamma + T_2 \sin\gamma) \times 44 = 38R_{AH}$

$(109.218 \sin 23.556 + 3{,}741 \sin 23.556) \times 44 = 38R_{AH}$

$\therefore R_{AH} = 52.27\text{N}; \ R_{BH} = 45.17 - 52.27 = -7.13\text{N}$

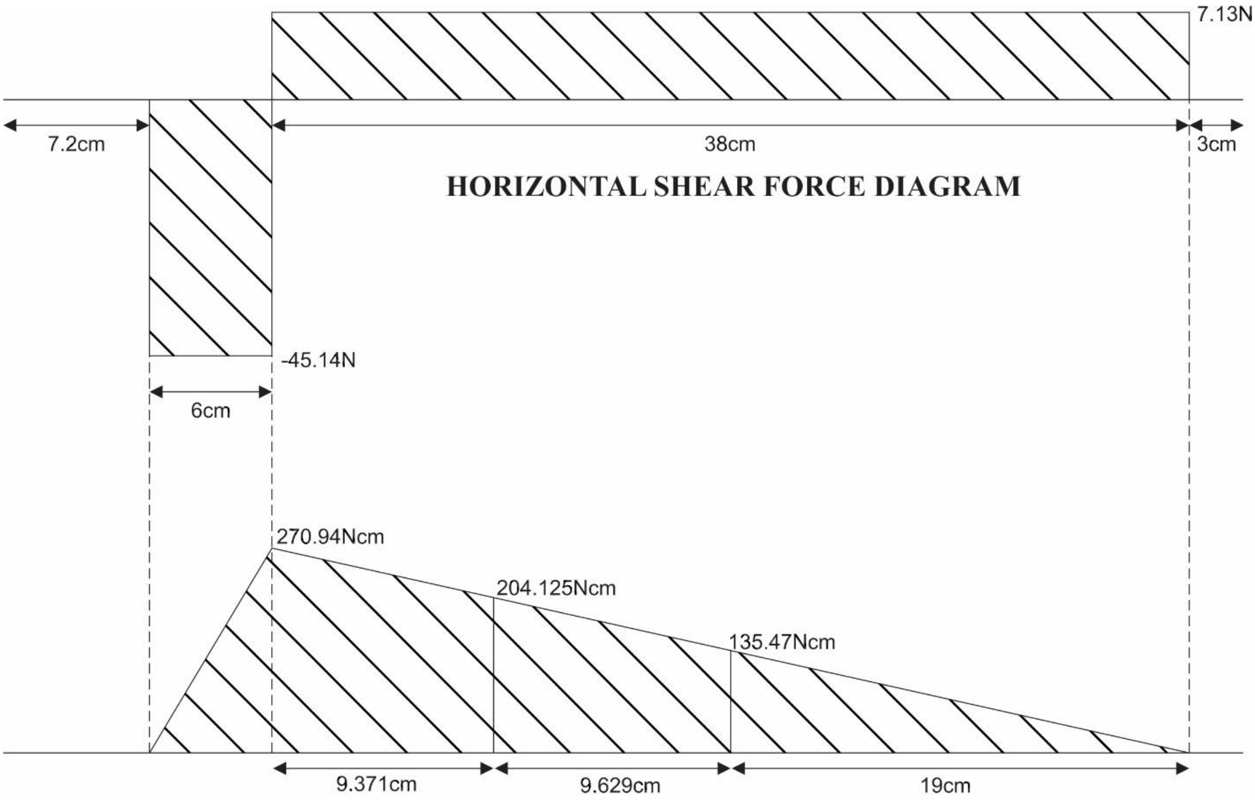
$\therefore R_{BH}$ is acting in opposite direction to R_{AH}. Therefore, the free body diagram becomes;

Figure 7: Resulting Free Body Diagram of Horizontal Forces on Shaft



Also, the shear force and bending moment diagram for horizontal forces gives;

Figure 8: Horizontal Shear Force and Bending Moment Diagram



Using the maximum shear stress theory for shaft subjected to combined twisting moment and bending moment;

$$\sqrt{[(K_m \times M)^2 + (K_t \times T)^2]} = \frac{(\pi \times \tau \times d^3)}{16} \quad (10)$$

Where K_m is the combined shock and fatigue factor for bending;

K_t is the combined shock and fatigue factor for torsion;

M is the maximum resultant bending moment on shaft;

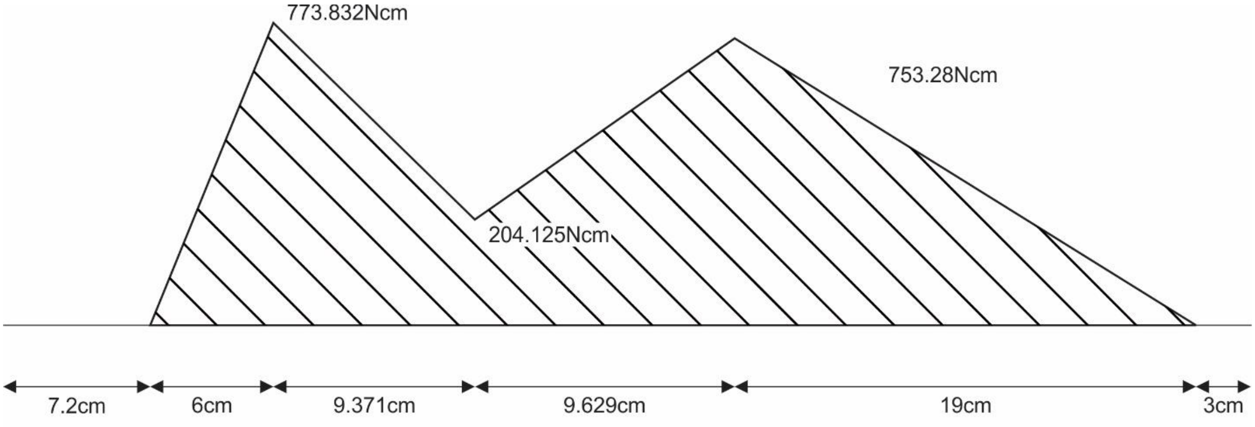
T is the twisting moment on shaft;

τ is the allowable shear stress;

d is the diameter of the shaft

Resultant Bending Moment Diagram gives;

Figure 9: Resultant Bending Moment Diagram



M = 773.832Ncm (maximum bending moment from bending moment diagram) = 7738.32Nmm
T = $\frac{P_D \times 60}{2\pi N_1}$ = $\frac{745,7\times 60}{2\pi\times 1179}$ = 6.04Nm = 6040Nmm.
Taking $K_m = 3$, $K_t = 3$ (Khurmi & Gupta, 2005); τ_{yt} of stainless steel is 204.6MPa (ASKZN, n.d.) $\therefore \tau_{ys} = 0.58\tau_{yt}$ = 118.67MPa

Using a factor of safety of 20 (Khurmi & Gupta, 2005)

$\tau = \frac{118.67}{20}$ = 6MPa

$\therefore \sqrt{[(3\times 7738.32)^2 + (3\times 6040)^2]} = \frac{6\pi\times d^3}{16}$

Solving for d;

d = 30mm.

3. Results and Discussion

The waste glass is loaded into the crushing chamber through the hopper which has a one-way flap to prevent escape of glass particles through the hopper. The 3 blades are joined to the shaft and equidistant to themselves, with the tip of the blades having a 10mm clearance from the inner radius of the crushing chamber. The shaft is driven by a one horsepower (1hp) electric motor at a speed of 1450rpm. The rotation of the blades attached to the shaft causes the fragmentation or disintegration of the waste glass as it smashes it and glass particles as small as 20μm were obtained with a glass crushing capacity was 230kg/h. The pulverized glasses or cullet are discharged through the 3mm perforations made on the lower part of the crushing chamber. The cullet is then passed or sent to the collector, from where it can be packaged for further processing or use as the case may be.

4. Conclusion

The rotary blade glass pulverizing machine was successfully designed and fabricated considering minimum power as very important parameter for an optimum output. This machine is a cost-effective means of crushing waste glass.

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